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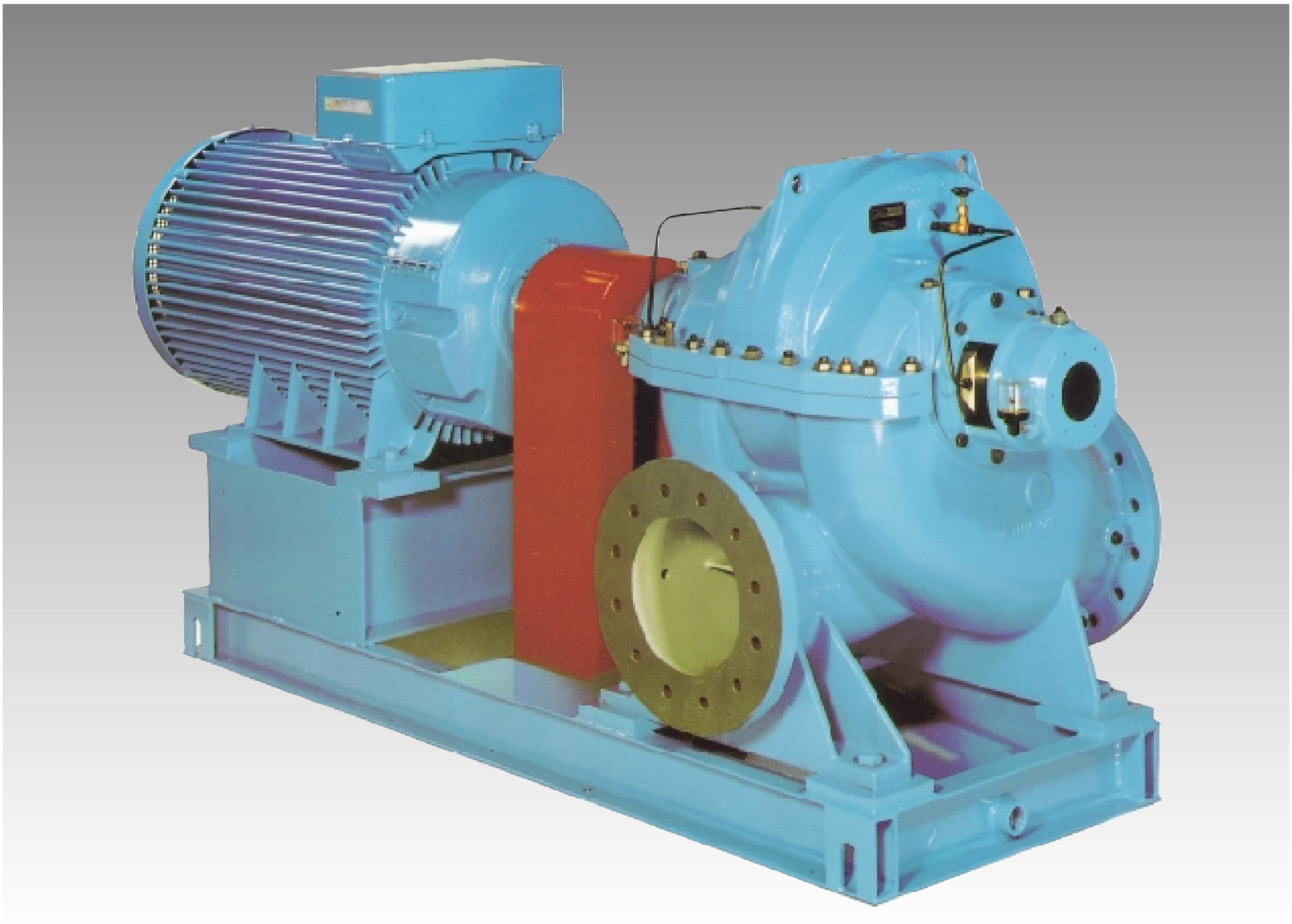
GOOD PRACTICE GUIDE 249

Energy savings in industrial water pumping systems



GOOD PRACTICE GUIDE 249

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

BEST PRACTICE
PROGRAMME

ENERGY SAVINGS IN INDUSTRIAL WATER PUMPING SYSTEMS

This booklet is No. 249 in the Good Practice Guide series and is aimed at those who are seriously concerned about how to reduce the costs of water pumping in industry. The Guide describes a variety of water pumping systems and the problems associated with them. The Guide also describes the opportunities that are available to make energy savings and gives examples and case histories showing how this might be achieved. An Action Plan is included to help those who wish to reduce the operating costs of water pumping systems.

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With acknowledgements to British Steel Technical, Swinden Laboratories, Moorgate, Rotherham, S60 3AR for their assistance.

Cover photo courtesy of Ingersoll-Dresser Pumps (UK) Limited.

First published Septmber 1998

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FOREWORD

This Guide is part of a series produced by the Department of the Environment, Transport and the Regions under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

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1. INTRODUCTION

Pumping costs UK industry over £1,400 million in electricity each year, mostly for pumping water, and estimates suggest that over 20% of this figure could be saved. On a typical industrial site, pumping is the single largest user of electricity and accounts for over 20% of the total electricity bill. It is, therefore, a key area to target for energy savings.

This Guide shows how energy savings can be achieved through the selection, control and maintenance of pumps and pumping systems on the basis of energy efficiency. Additional (less quantifiable, but nevertheless valuable) cost savings can also be made through associated reductions in wear and maintenance requirements, and less unplanned downtime.

This Guide provides information on industrial water pumping systems, but the general principles can also be applied to other pumping requirements. It is an excellent introduction for all personnel involved in the purchase, design or maintenance decisions relating to water pumping systems in industry. The Guide also includes case histories which show the energy savings made at sites implementing energy-saving measures, together with references for further information.

In addition to reducing the costs of water pumping, considerable savings in the supply and disposal costs of water can be made from reviewing and reducing water use.

1.1 Why Aren't Widespread Savings Being Made?

Many opportunities for reducing pumping costs are not recognised because:

- the basic principles of pumping are often misunderstood;
- provided pumps are running and delivering sufficient water they are considered to be functioning satisfactorily;
- production concerns outweigh pumping considerations;
- there is a lack of awareness of pumping costs;
- life-cycle costs (i.e. initial costs plus running and maintenance costs) are rarely considered at the design stage.

1.2 How Can This Guide Help?

To help address some of these issues, this Guide provides information on:

- basic operating principles of water pumps;
- typical pumping systems;
- typical problems encountered;
- possible solutions to problems;
- case histories;
- an **Action Plan** (see Section 6) aimed at reducing operating costs.

2. WATER PUMPING PRINCIPLES

2.1 Pump Running Costs

An example of a pump typical of many found on industrial sites can help to illustrate pump running costs

Example

A pump delivers 150 m^3/hour of cold water into a 20 m head with 80% efficiency, and is driven by a motor with 90% efficiency. For a typical average industrial electricity cost of 4.5 p/kWh, how much does it cost to run the pumpset continuously for a full year?

150 m^3/hour = 42 litres/second (l/s)

$$\text{Power absorbed} = \frac{42 \text{ l/s} \times 9.81 \text{ m/s}^2 \times 20 \text{ m} \times 1.00^{1}}{0.80 \times 1000}$$

$$= 10.3 \text{ kW}$$

$$\therefore \text{Motor input power } \frac{10.3}{0.90} = 11.5 \text{ kW}$$

$\therefore$ Annual running cost = 11.5 kW x 24 hours x 7 days x 52 weeks x £0.045/kWh

= £4,500

For comparison, if the pump were run through a double-shift working week for 48 weeks only, the running costs would be:

11.5 kW x 40 hours x 2 shifts x 48 weeks x £0.045/kWh = £2,000 or 56% less

Therefore, in general terms, an 11 kW pump costs between £2,000 and £4,500/year to run.

2.1.1 *Pump and Motor Purchase Costs*

For the pump and motor used in the above example, the approximate purchase costs to an industrial purchaser might be £1,200. Comparing this with the running costs, it can be seen that the equivalent of the capital cost for a new pump plus motor may be consumed within four months.

2.1.2 *Lifetime Costs*

Various figures have been quoted for the lifetime costs of a pump, but in general they suggest that for a pump lifetime of, for example, 20 years, the costs as percentages of the total are thus:

Initial capital cost of pump + motor	2.5%
Maintenance costs	2.5%
Running energy costs	**95%**

[1] Note that the specific gravity of water falls to 0.96 at 100°C.

The main conclusion to be drawn from these figures is that running costs far outweigh capital costs and should be considered as far more important when specifying new equipment. Pumps and motors should be sized according to short-term requirements. If they are oversized to cater for potential increases in water demand, then running costs, as well as capital cost, will be elevated. The extra costs incurred may be greater than the cost of replacing pumps should the need for greater pumping capacity arise. With the costs of pumping representing such a significant cost to industry, it is important to maintain pump operation at high efficiencies, and to minimise ineffective pumping. In general, pumps and their operation should be well matched to the water requirements of the process.

The characteristics of different types of pumps and the choice of pumps to match the system are described in Appendix 1.

3. TYPICAL INDUSTRIAL WATER PUMPING PROBLEMS

Many industrial pumping systems will have been in operation for more than 20 years. Modifications to the process, throughput, or the system may have changed the water demands, with pumps being expected to cope with completely different circumstances from the initial specifications. This, and inadequate attention to maintenance, results in inefficient operation of pumps.

This Section examines common problems found on site in pumps and pump system design. Before optimising the pump and pumping system, it is important to ensure that the actual water use is not unnecessarily high. This Section starts by looking at typical reasons for excess water demand in a major user of water pumps - water cooling systems.

3.1 Unnecessary Water Use in Cooling Systems

It is unlikely that all water-cooled equipment requires cooling at all times. There may be exceptions, such as furnace components (where some cooling is necessary while the furnace remains hot), but many items are part of intermittent processes which may be stopped for either planned or unplanned reasons. Even under production conditions, some items of plant might be omitted from the production route and need no cooling. Also, there are many plants which do not operate at weekends.

The water demands of processes are variable and intermittent but this is often not recognised as far as water pumping systems are concerned. They are set to satisfy maximum demand and left running at that setting. Some pumps run at weekends, just to satisfy the requirements of a single piece of equipment that needs cooling.

At times when items of plant are not in use and do not require cooling water, their supply is often diverted, usually straight to the return. In such circumstances water is merely being recirculated having served no useful purpose. Some diversion pipes include restrictions which help to reduce the diverted flow and hence the pumping power being used. Other divert routes are deliberately contrived to maintain water pressure by diverting full flow straight to the return.

3.2 Multiple Pumpsets Multiplying Problems

Several sets of pumps can be involved in recirculating water and so excessive amounts of water distributed by supply pumps require extra energy from other pumps in the system to recirculate the excess. Extravagant or unnecessary water use elevates the pumping costs at all the pumps within the recirculating system.

3.3 Wasteful Balancing of Systems

The complexity of typical open-circuit water systems favours simple operation based on static control, i.e. it is easiest for the operators to set up the systems so that the supply pumps deliver sufficient water to meet maximum demand at all times, whether required or not, and to arrange for all return pumps to cope with this quantity. In this way a static balance can be achieved which always satisfies the process demands, but wastes energy.

3.4 Oversized Pumps

Not only water requirements can be over-designed, the pumps selected to supply the water can also be over-designed. It is common practice to add approximately 10% to the estimated frictional losses of a pipework system design, then to specify pumps based on the elevated figure, resulting in oversized pumps. This practice has developed to allow for any fall-off in pump efficiency through wear, and to allow for any pipework fouling which may occur as the system ages. However, oversized pumps cost more to purchase, and because they are not operated at their peak efficiency flow they also cost more to run.

3.5 Inefficient Pump Control by Throttling

Throttling is effective in reducing flow from pumps, but is not an efficient method because of the energy wasted across the throttle, although it is widely used as a flow setting or controlling technique. Ideally, pumps should be operated within a range of flows centred around peak efficiency flow if problems are to be avoided and high efficiency achieved. Therefore, the range over which throttling should be employed, if it is employed at all, is limited.

As a consequence of over-design, most industrial pumps are found to be operating at less than the peak efficiency flow, i.e. throttled to some degree. They cannot, therefore, achieve their maximum efficiency and although they are using less power than they would at full flow, energy is being wasted in all these systems.

Throttling is usually applied by using a valve on the outlet of a pump to vary the flow. The effects of this can be illustrated using pump characteristics, as in Fig 1.

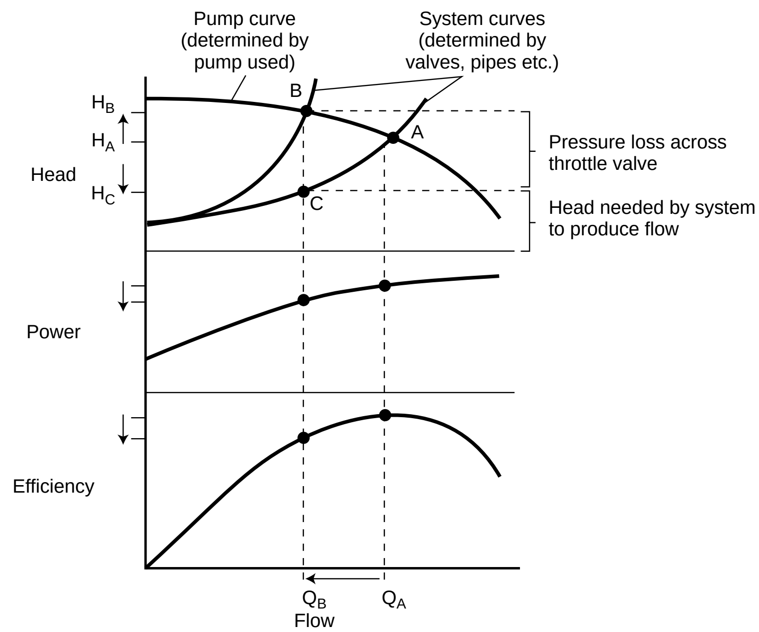

Fig 1 Illustration of the effect of throttling a pump

Assume that a pump and its system are well matched such that the normal system resistance line crosses the pump head/flow curve at a point, A, corresponding with peak efficiency flow, Q_A. By partially closing the throttling valve the flow is reduced to Q_B as the system resistance increases according to a new line which crosses the head/flow curve at B.

Under these circumstances the pressure head generated at the pump outlet has risen from H_A to H_B, although the useful head has fallen from H_A to H_C. Therefore the difference between these two values is equivalent to the head loss across the throttling valve, i.e. the wasted energy.

The efficiency has also fallen, i.e. less of the energy being absorbed by the pump is being converted to pressure and flow.

The power required by the pump has fallen by a small amount, but not by as much as might be expected. This is because even at zero flow, the pump will absorb some power (very roughly around half of the power absorbed at peak efficiency).

3.6 Less Efficient Impellers

For each pump there is a range of impeller sizes which can be fitted, each size producing different pump performance. Often pump characteristics are displayed as in Fig 2 to demonstrate this.

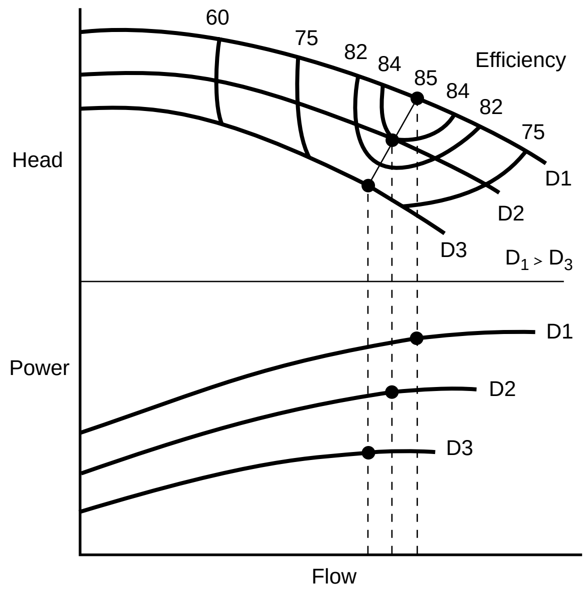

Fig 2 Pump characteristics showing various impeller diameters

The characteristics usually show maximum and minimum permissible diameters, plus one mid-range. Note that the maximum efficiency value is usually achieved with the largest impeller size, in this example 85% with impeller diameter D1. The peak efficiency value falls off as the size decreases. However, the peak efficiency flow also decreases. System designers make use of this fact by opting to use pumps that can achieve the desired duty with less than the maximum impeller size. This allows them to fit a larger impeller at some later date should the water requirements increase. Unfortunately, this can lead to a larger pump than necessary being fitted, and can also cause a marginal loss of efficiency.

The important points to note here are that:

- a pump fitted with a reduced-size impeller will be less efficient than a smaller pump fitted with a full-sized impeller when matched to the same duty;

- although smaller impellers are less efficient they also develop less head and flow whilst using less power.

3.7 Oversized Pump Motors

When selecting a motor to match a pump it is common to choose one which is sufficient to meet the power requirement at the right-hand end of the pump characteristic, i.e. to cater for ‘end of curve run-out’. It is unlikely that this will fall right on the mark for a particular size, therefore the next size up of motor will be chosen. In an oversized pump which is throttled to run at less than optimum flow, this could mean that the motor is only lightly loaded. In such a case, although extreme, the motor efficiency could be a few per cent less than at full load.

3.8 Misuse of Parallel-pumps

For many reasons, such as avoiding motor overload or for security of supply, pumps are often used in banks of three or more. In a bank of three it is usual to find two running and one on standby.

Contrary to commonly held beliefs, the flow does not double on addition of a second similar pump in parallel. In fact each successive pump adds a smaller amount to the total head and flow (although the total flow is split equally between the pumps).

We can examine the characteristics of two-pump operation by two examples:

In the first example, illustrated in Fig 3, the system resistance is ideal for one-pump operation and would produce a flow of Q_1. By adding in the second pump, of identical size and condition, the total flow moves to Q_2, corresponding with point A where the system resistance line crosses the two-pump curve. Each individual pump delivers half this flow and operates at point B, using a smaller amount of power (though twice that power is used in total) and operating at a lower efficiency. The net difference is a small gain in head and flow for a significant increase in power.

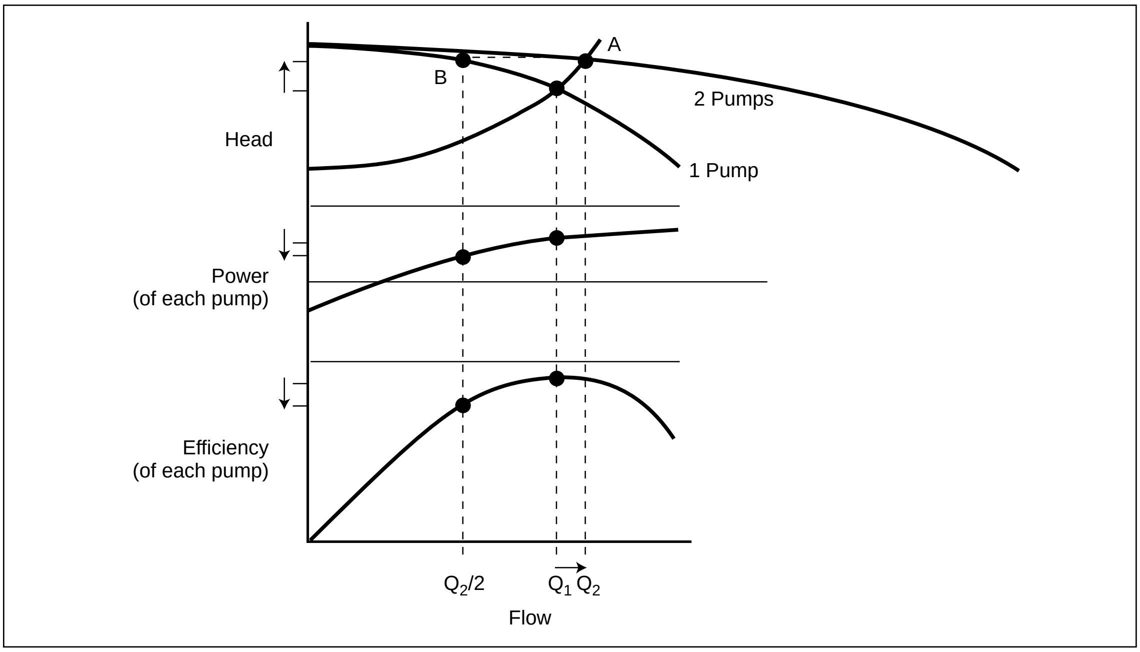

Fig 3 Parallel-pump operation - designed for a single pump

Pumps operating as a pair in parallel should be matched with the system such that each of them operates close to its peak efficiency flow.

The second example, illustrated in Fig 4, shows ideal system resistance for two-pump operation.

Under these conditions it is inadvisable to switch off one of the pumps. If this were done, the remaining pump would assume operation at point C towards the end of its curve, where lack of net positive suction head ($NPSH_A$) and motor power limitations might cause problems. $NPSH_A$ is defined and explained in Fig 28, Section A1.3.

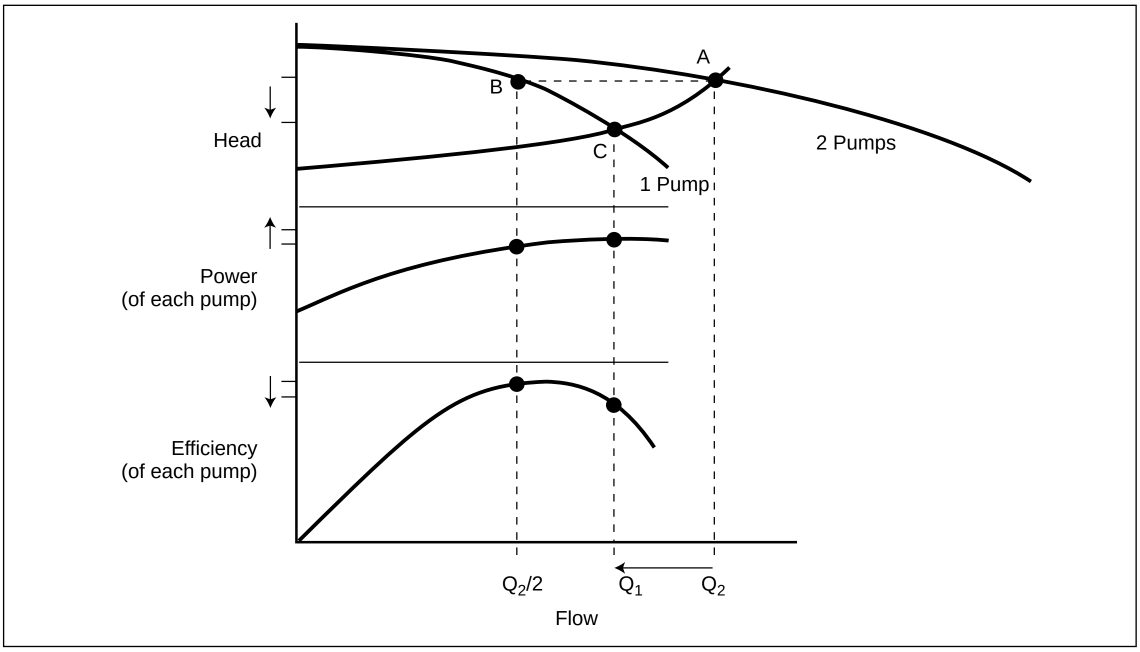

Fig 4 Parallel-pump operation - designed for two pumps

Occasionally, pumps are used in banks of more than three, although it is rare to find more than six in parallel. This arrangement is sometimes used to give a degree of flexibility to the quantity of water pumped. However, the benefits are not always as expected.

Fig 5 illustrates how each successive pump adds a smaller amount to the total head and flow (although the total flow is split equally between the pumps). Therefore, when operators decide to ‘add another pump’ to ensure they have enough water available, they could be achieving very little, whilst generating additional costs. Changes in system resistance would be required to maximise the benefits of varying the number of parallel-pumps in use.

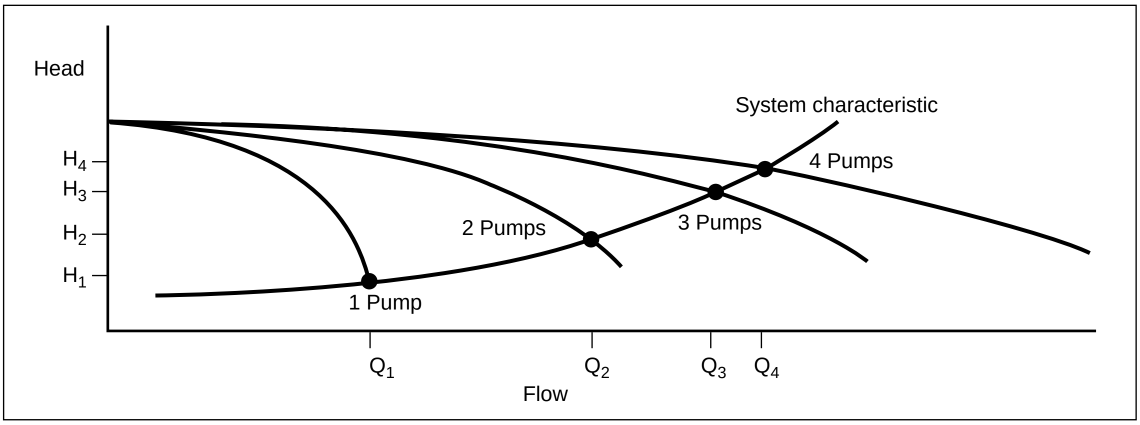

Fig 5 Multiple pumps in parallel

3.9 Pump Wear

The main cause of pump wear is poor water quality. High concentrations of particulates and low pH values are common problems which cause wear through erosion and corrosion. They are normally partially controlled by filtration and water treatment, although some degree of wear is inevitable. Cavitation damage can also cause wear and thus impair pump performance.

Typical wear problems are: internal leakage between high pressure and low pressure sides of a pump through neck ring seals; impeller wear; and casing wear.

When a pump wears it tends to shift its performance characteristics as shown in Fig 6. Generally (although not necessarily) a worn pump tends to generate less flow and head whilst operating less efficiently (therefore requiring more power), i.e. worn pumps cost more to run to achieve the same flow.

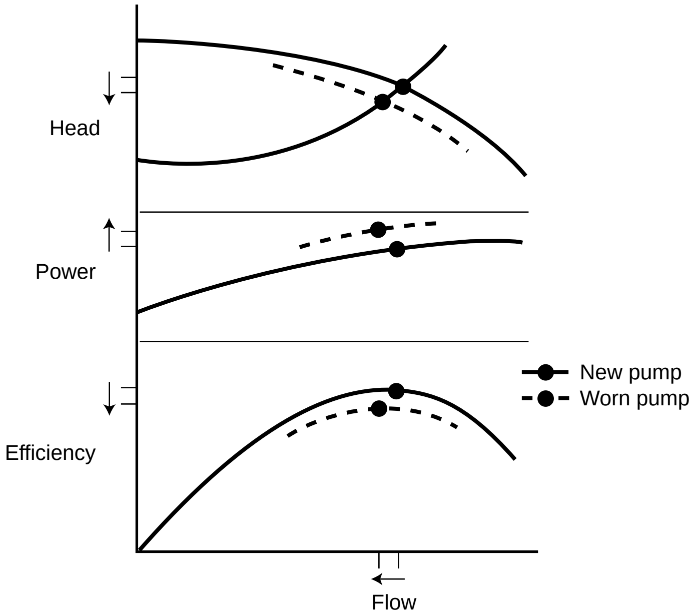

Fig 6 Effect of wear on pump characteristics

Data collected from many pump tests have been averaged to produce the trend for pump wear shown in Fig 7.

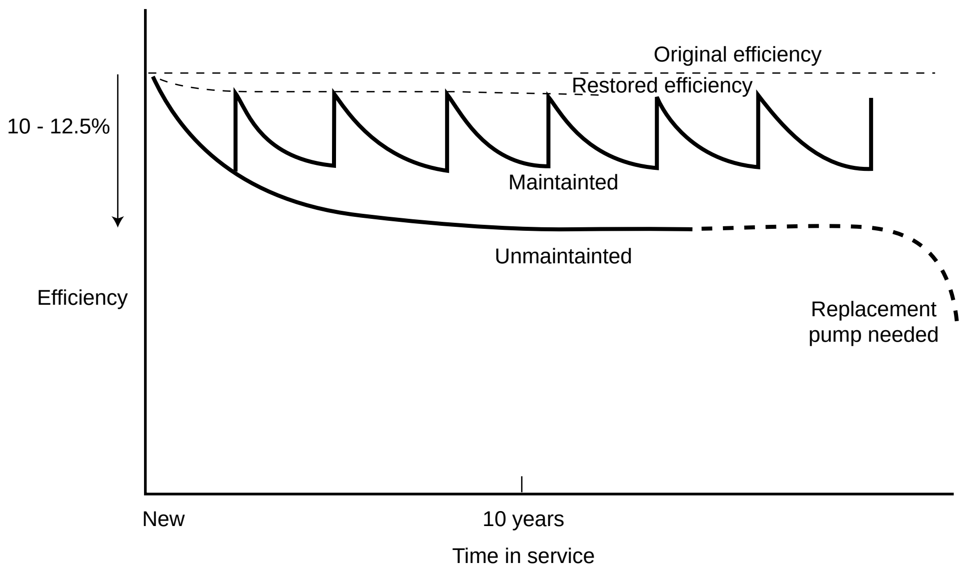

Fig 7 Average wear trends for maintained and unmaintained pumps

This trend suggests the following:

- much of the wear occurs in the first few years until clearances become of similar size to the abrading particulates;
- after about ten years the wear tends to level out;
- the overall drop in efficiency for an unmaintained pump can be around 10 - 12.5%;
- an unmaintained pump can reach catastrophic failure after around 20 years' service.

Section 2.1.2 shows that the lifetime energy costs are 95% of the total lifetime costs of ownership, and so a 10% deterioration in efficiency represents an increase of about 11% in the lifetime costs of ownership.

Periodically maintaining the pump, by refurbishing/replacing the neck ring and impeller, can return efficiency to a level close to that when new. It is important to note that the data are an average for many pumps and that poorly maintained pumps can fail catastrophically in a very short time.

3.10 Pump Inlet Restrictions

To help prevent solid matter from being drawn into pumps they may be fitted with some form of inlet filter, e.g. a wire mesh basket. Unless these filters are kept clear and unblocked they can cause low pressure at pump inlets, i.e. lack of $NPSH_A$. In some cases this leads to a loss of pumping efficiency, but in extreme cases cavitation occurs within the pumps causing physical damage.

3.11 Poorly-designed Pipework Adjacent to Pumps

Traditionally, pumps were fitted with flared pipe sections on their inlet and outlet. At the inlet side this accelerates water towards the pump and helps keep pipework resistance down, i.e. $NPSH_A$ up. At the pump outlet, correct water velocities require greater diameter pipework than the pump outlet flange size. In both cases a flared section of gradient around 1:20 should be used. In some newer installations flares have not been fitted, or where they have been used they have a steep gradient or are stepped. Worse still, the adjoining pipework often turns one or more 90° bends of fairly tight radius close to the pump. Such practices can lead to increased turbulence at the pump inlet and outlet, producing vibration and possibly mechanical damage.

3.12 Jammed Non-return Valves

Most banks of parallel-pumps are fitted with non-return valves as shown in Fig 8. Ideally, the valves should create very little pressure drop when fully open on running pumps, and form a good seal when pumps are not running. Poorly maintained valves can stick partially open, or partially closed. When not fully open the extra system resistance created forms an effective throttle on running pumps. If not fully closed on standby pumps, the valves can pass water, which should have been delivered to the process, through the pumps, causing them to rotate in the reverse direction. In both cases, pumping efficiency is impaired and a reduced flow is produced.

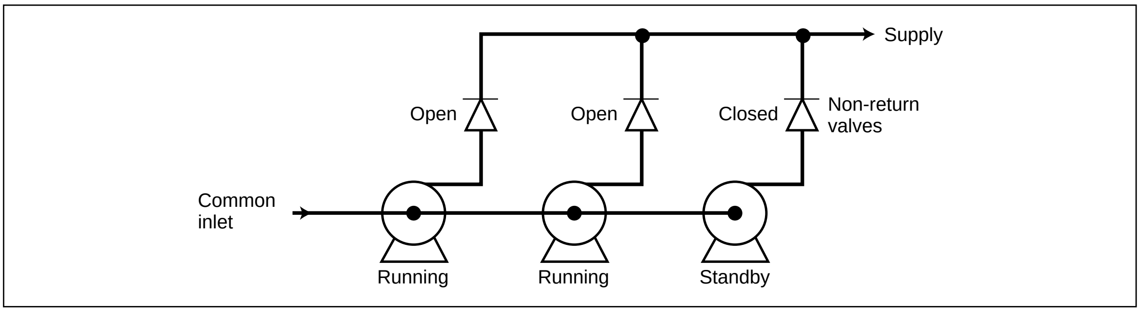

Fig 8 Schematic of a three-pump bank with non-return valves

3.13 Inappropriate Water Velocities

Designers of pipework systems should aim for water velocities of around 2 m/s by selecting appropriate pipework diameters. Lower velocities can lead to silt collection and eventually rotting pipework. Higher velocities lead to increased system resistance, which requires increased pumping power. They can also increase abrasive wear on pipework and valves, especially if the water contains particulates.

3.14 Inadequate Metering, Monitoring and Control

Metering equipment on pumping systems is often inadequate, so little attention may be paid to the system as long as the water supply is satisfactory. However, the pumps may be operating inefficiently at high costs. Ammeters and inlet pressure gauges are basic metering, and should be present on all pumps. Other metering equipment can include flowmeters, but these tend to be fitted only to the vital supplies. In some cases the results from water system metering are logged but this tends to be purely for reference in case of incident or failure. Rarely are such figures used to identify the potential for pumping system changes or for monitoring energy use. Sensible, cost-effective monitoring and regular analysis of results can provide useful information to improve operating costs. Further details on this subject are available in Good Practice Guide (GPG) 91, *Monitoring and Targeting in large manufacturing companies.*

Since there is a general lack of metering equipment, water systems are largely unmonitored, making problems difficult to detect. The quantities of water pumped and the energy consumed are often unknown. This makes control of pumps and systems relatively crude, relying mainly on manual intervention rather than automatic adjustment.

Flow control valves are employed in some systems where a variable quantity of water is to be delivered, e.g. cooling water supplies. These devices are effective in controlling flow but they also create other changes. They create some pressure drop in order to function correctly, but at the same time excessive upstream pressures are commonly found and so add to the wasted pumping energy.

Modern technology, such as variable speed control of pumps is making some impact on industrial pumping costs, although the uptake is quite slow. Further details on this subject are included in GPG 2, *Energy savings with electric motors and drives.*

3.15 Inadequate Documentation

With so many industrial pumping systems of considerable age it is not surprising that documentation on systems and components is often poor. Many pumps do not have original characteristics, although design duty details are usually held on record. Since the original installation, there may have been many modifications to systems and water requirements, which may not have been well documented. Without such details it is difficult to ascertain pump capabilities, true system requirements and the scope for savings. There is also no basis for comparison of subsequent monitoring. Where original data do exist, it should be noted that subsequent deterioration, even with appropriate refurbishment, will mean that the pump may not meet the original specification.

3.16 Summary

The main problems can be summarised as follows:

- pumps can operate inefficiently through over-design, wear and the extensive use of throttling as a static control technique;

- lack of maintenance on pumps and systems can exacerbate problems;

- pumped quantities can be excessive through over-design and safety margins or through arbitrary judgement of cooling needs;

- water can be pumped unnecessarily to inactive plant items;

- systems are often set to accommodate maximum water demands but cannot cope efficiently with demand changes;

- diversion and recirculation are employed as crude control techniques, but these waste energy;

- new technology that helps match pumping with water requirements is becoming more common, but is being introduced slowly and with caution;

- operators may be unaware of wasted energy and high pumping costs, through the lack of metering equipment and monitoring;

- without system documentation some operators may be unaware of their system details and true water requirements.

All of these factors contribute to the high pumping costs within industry. Some can be remedied with little or no capital outlay. Others require investment but can produce savings that give very attractive short payback periods followed by continued savings.

4. COST SAVING OPPORTUNITIES

Having examined typical industrial pumps and pumping systems, and identified the many problem areas, possible solutions must be considered. These solutions can be grouped under the following headings:

- maintaining;
- modifying equipment or operation;
- monitoring.

4.1 Maintaining

In order to restore a worn pump to an efficiency close to its original value, it must be at least partially refurbished. This may include replacing the rotating element (the impeller plus its neck rings), the bearings and the seals. This is a comparatively simple operation on a split-casing pump, but it may cost several thousand pounds as the rotating element is its most costly component. Also, the casing will not be restored to the original internal dimensions, therefore some efficiency loss (compared with original characteristics) will remain.

The benefits of refurbishment have to be judged on individual merit, but as with all savings options involving pump performance improvement, it should be borne in mind that running costs predominate in the lifetime cost breakdown and that small increases in pump efficiency can produce worthwhile savings. Note that a worn pump produces less flow, and if this is proved adequate, on completing refurbishment the pump flow should be set to the lower value in order to obtain the maximum savings benefit, as illustrated in Fig 9.

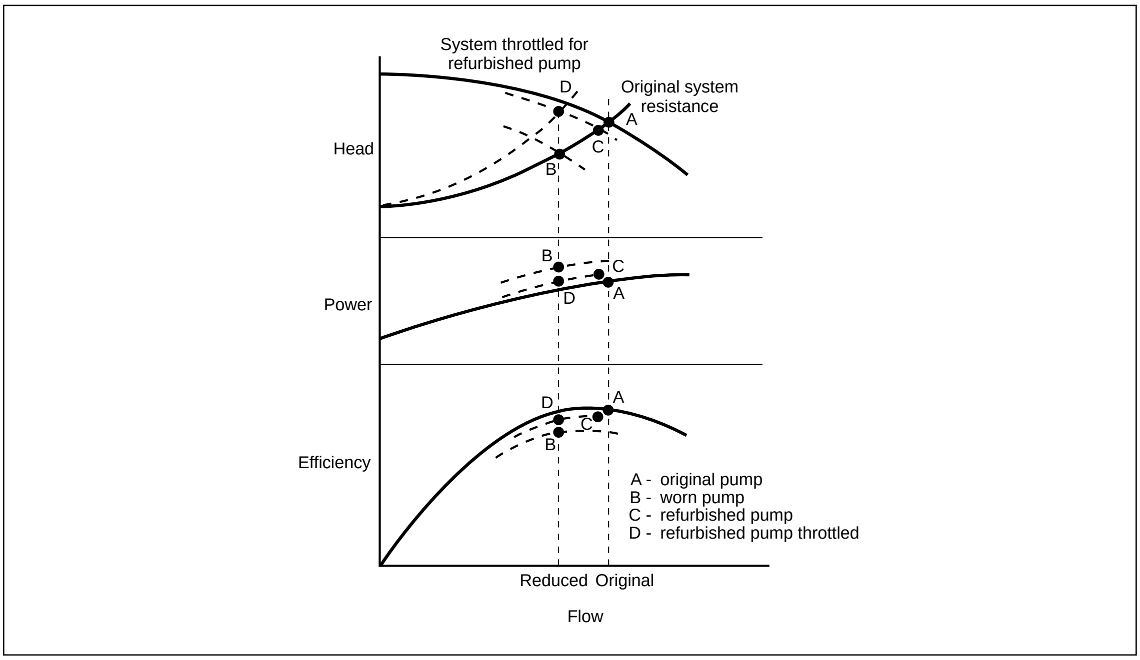

Fig 9 Effect of refurbishment on pump characteristics

Other opportunities for maintenance actions to contribute towards savings include:

- routine cleaning of pump inlet filters;
- routine checking of non-return valves;
- curing leaks.

4.2 Modifying Equipment

4.2.1 *Internal Coatings*

A range of materials referred to as **coatings** have been developed for applying to the internal components of pumps to modify the surface properties of the host material.

Corrosion/Erosion Resistant Coatings

These coatings can be applied where conditions are severe because of a need to pump corrosive liquids or liquids containing abrasive particles. The coatings help prevent exposed surfaces from being worn away, and maintain component dimensions and clearances. Efficient operation is therefore sustained and the need for pump maintenance is reduced. Such coatings need to be applied to all of a pump's internally exposed surfaces, including the impeller.

Low Friction Efficiency Enhancement Coatings

Low friction coatings tend to be less robust than corrosion/erosion resistant coatings but do afford good corrosion resistance where applied. However, their main purpose is to provide an extremely smooth surface (compared with the host material) and create less friction with the high velocity water inside the pump. In this way the pump can produce elevated pressure and flow for a similar (or reduced) power input. A coated pump can, therefore, be more efficient.

New pumps can be coated on purchase to give a higher efficiency than an uncoated pump by around 2 or 3%. Worn pumps can be coated (with appropriate preparation) and will exhibit an efficiency improvement, although results are less predictable.

Low friction coating materials are normally either glass-flake-based or polymer-based. The latter can be applied very thinly so that the hydraulic dimensions within the pump are barely changed. However, glass-flake based coatings are considered to have better adhesion to the host metal, but can be 1.5 to 2 mm thick. When using a thick coating on a new pump, efficiency improvement tends to be confined to flows lower than the design flow, and the peak efficiency flow can be reduced, as illustrated in Fig 10.

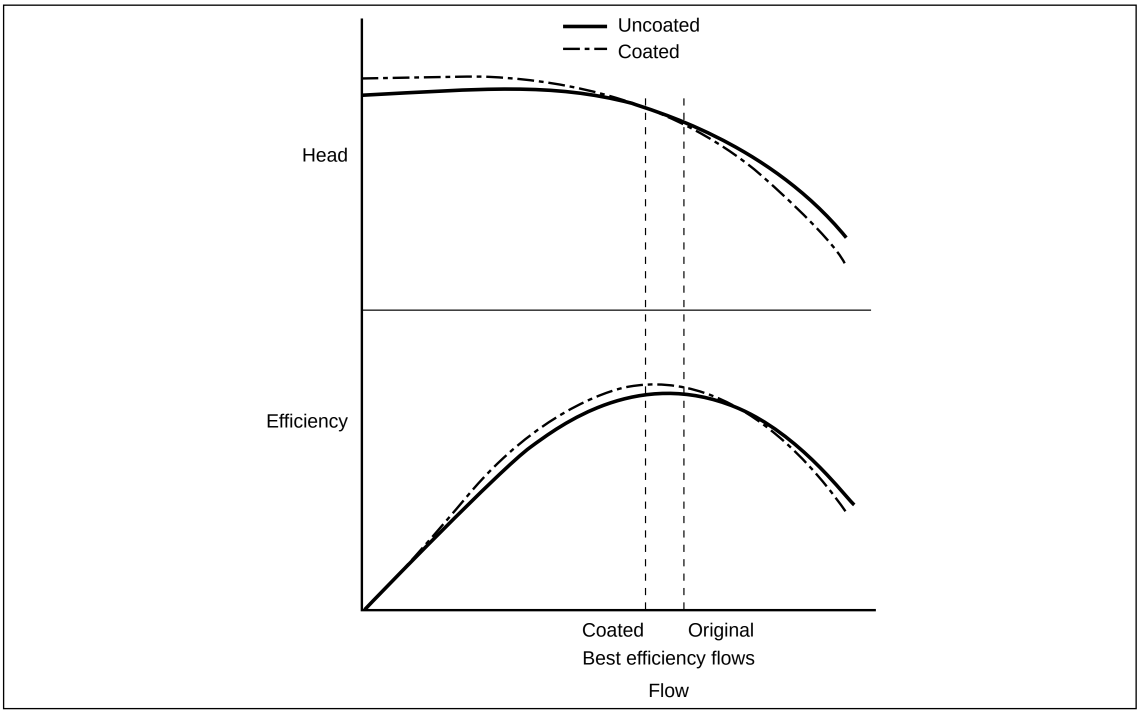

Fig 10 Potential effect of coatings on new pump characteristics

However, most pumps are over-designed and tend to operate to the left of their peak efficiency flow, thus as the flow is reduced by the coating, an efficiency improvement can be expected. On worn pumps, although wear will be localised rather than uniform, the thicker coating may be more beneficial in restoring internal dimensions around the wear areas. Worn pumps will usually be coated at the same time as being refurbished and, unlike normal refurbishment work, efficiency can be restored to the original value, or above.

Preparation for coating includes sandblasting and chemical testing to ensure that the host metal surface to be coated is sound and salt-free. A multi-layer coating application follows. The whole process is usually conducted by specialists, although some coatings can be applied on-site under supervision.

With efficiency enhancement coatings it is usual to coat only the casing and the outer faces of the impeller to reduce the main frictional losses, i.e. casing surface finish loss and disc friction loss.

In summary, the benefits of efficiency enhancement coating are:

- an improvement in pump efficiency which can lead to reduced running costs;
- some extra corrosion resistance on the parts coated;
- prolonged high efficiency performance compared with an uncoated pump.

4.2.2 *Changing Impeller Sizes*

As has been mentioned earlier in this Guide, the type of pumps in common use within industry can be fitted with a range of impeller sizes. Maximum efficiency is usually available only with the largest size impeller, as illustrated in Fig 11.

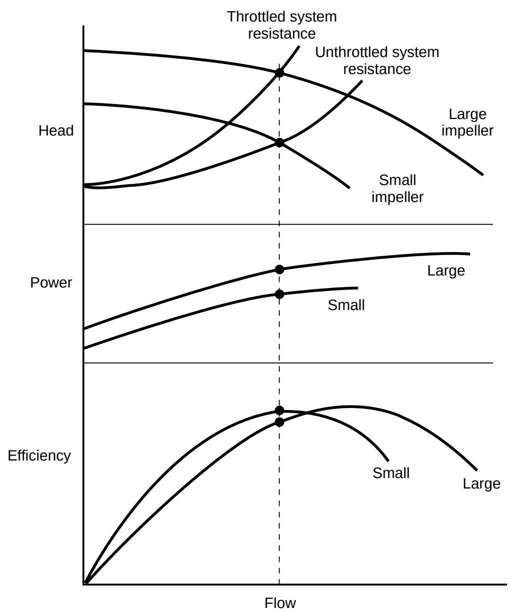

Fig 11 Effect of reducing impeller diameter on pump characteristics

The range of acceptable sizes is often shown on manufacturers' characteristics for a particular pump, otherwise the generic curves for the pump type showing the impeller size range should be available from the manufacturers.

In some circumstances, the range of impeller sizes can be used to save pumping energy. For example, if a pump is always throttled to some degree and not operating at peak efficiency, then it may be possible to use a smaller impeller to generate a similar flow at a lower head (while opening the throttling valve) and thereby demand less power. This method of matching pump performance with water requirements would be an expensive option if it entailed purchasing a new rotating element. However, the existing oversized impeller can be removed from the pump and trimmed in a lathe to reduce its diameter and achieve the desired results. Obviously this is a one-way procedure which should not be undertaken without guidance from pump experts. Nevertheless, it is a valuable technique which is commonly applied in order to change pump operating performance and save pump energy.

> Good Practice Case Study 300, *Energy savings by reducing the size of a pump impeller,* shows how Salt Union trimmed a pump impeller on a condensate pump driven by a 110 kW motor and made energy savings of £8,900 a year.

4.2.3 ***Using Smaller Pumps***

This can be an economic option if:

- pumps are too large for their maximum duty;
- pumps are less than around 80% efficient at their maximum duty;
- energy use is high, i.e. where large pumps are running for long hours.

For example, if a pump has to be throttled to produce the required maximum flow it may be possible to employ a smaller pump that is designed to deliver this flow more efficiently, as illustrated in Fig 12.

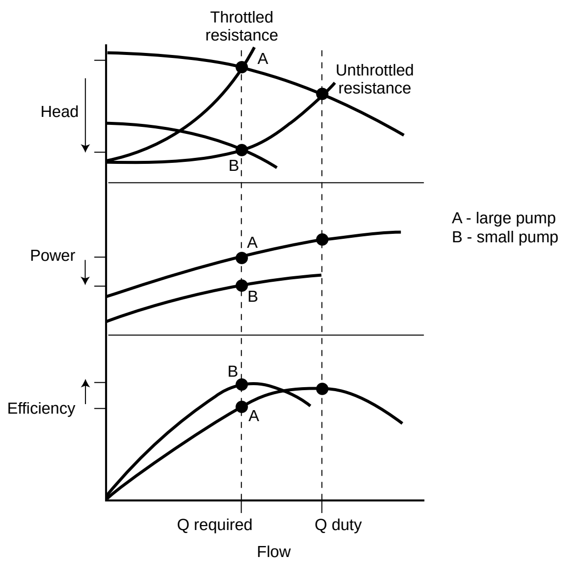

Fig 12 Effect of using a smaller pump

4.2.4 *Higher Efficiency Motors*

While the efficiency of the motor will usually significantly exceed that of the pump it is driving, cost-effective ways of reducing motor losses should not be overlooked, in particular through the use of Higher Efficiency Motors (HEMs). HEMs are on average three percentage points more efficient than standard efficiency motors, although this improvement decreases as the motor size increases.

Now that HEMs are available from some manufacturers with no cost premium, they should be specified for all new applications, and HEMs also give further benefits through an improved power factor. Like pumps, motor efficiency falls off with load, and so it is important not to use unnecessarily over-sized motors. On average, motors are found to be operating at just two-thirds of rated power, and so some more recent designs are designed for maximum efficiency at this rather than full load power.

When a motor fails the decision must be taken to replace or repair it. If it is decided to repair the motor, then to minimise efficiency losses during repair, ensure that it is repaired in accordance with the joint AEMT/EEBPP Good Practice Guide on this subject (*The repair of induction motors - best practices to maintain energy efficiency,* available from the AEMT. Contact details are given in Appendix 2).

GPG 2, *Energy savings with electric motors and drives,* discusses in more detail the selection and control of motors for minimum energy costs.

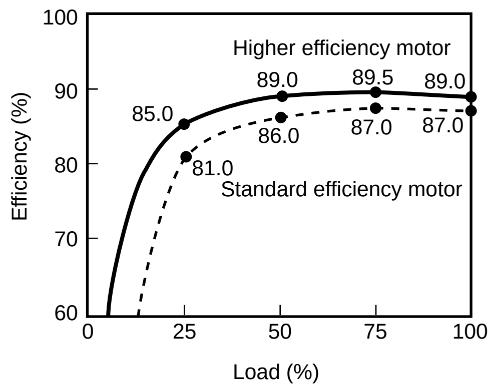

Fig 13 Variation in efficiency with load for a standard and a higher efficiency 7.5 kW induction motor

4.3 Modifying Operation

4.3.1 *On/Off Control*

If periods can be identified when water is not required, then it may be possible to switch off pumps until the water is needed. This can be done manually, but simple control measures may be appropriate, e.g. level switches, temperature switches, timers.

Frequent re-starts are inadvisable because they generate shock loads and high motor currents which produce heating effects. The use of on/off control may be limited, therefore, to lengthy stoppages (where predictable), downshifts and weekends.

4.3.2 *Soft-starting*

A **soft-starter** is an electronic unit that fits between a motor and its electricity supply. It provides smooth, gentle motor acceleration which prevents shock loading and reduces the heating effect on the motor. It also reduces water hammer and surges. Therefore an increased re-start frequency is tolerable, allowing pump users to take advantage of the many instances of short duration when water is not required, e.g. during production stoppages and delays, or when tanks are full/empty. Further details on this subject are available in GPG 2, *Energy savings with electric motors and drives*, and New Practice Final Profile (NPFP) 79, *Variable Speed Drives on a steel mill's water pumping system.*

4.3.3 *Variable Speed Pumping*

The pump characteristics discussed so far have been those resulting from fixed speed operation. However, by reducing the motor speed, and hence pump speed, it can be seen that a family of characteristics can be generated throughout the speed range as shown in Fig 14.

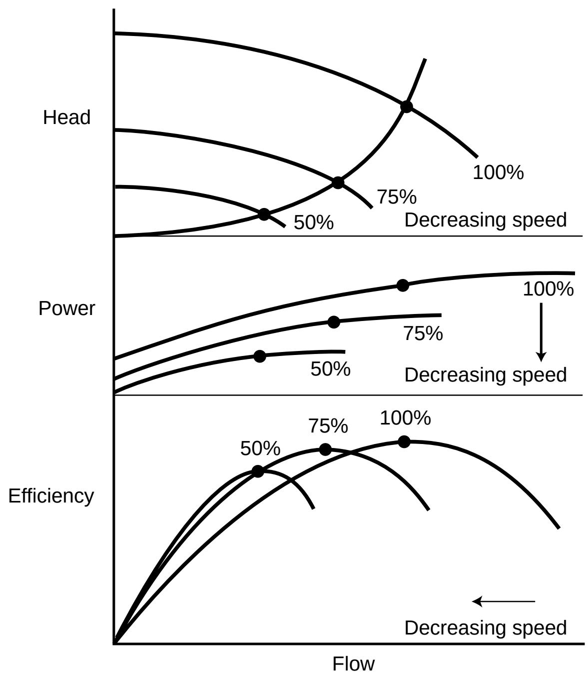

Fig 14 Effect of speed reduction on pump characteristics

Represented another way, as in Fig 15, it can be seen that the efficiency remains high at flows between 60% and 100% of the design flow. At lower flows the efficiency falls off rapidly, although this varies with pump size and is less severe with larger pumps.

Case Study examples of energy savings from the use of Variable Speed Drives (VSDs) to control pump speed are included in Section 7.

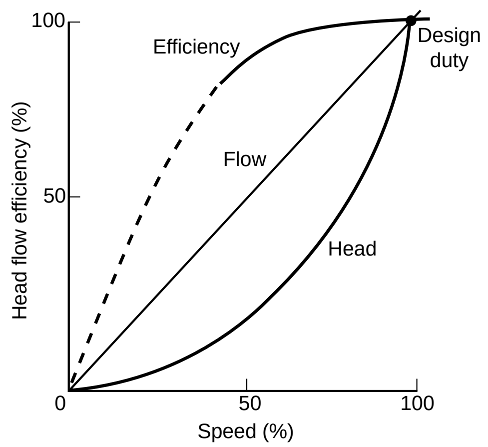

Fig 15 Variation of head, flow and efficiency with pumping speed[2]

The variation of pump performance with speed is usually described by the Affinity Laws, which state that:

Flow	α	Speed
Head	α	$Speed^2$
Power absorbed	α	$Speed^3$

So, at 50% speed a pump generates 25% head and absorbs only 12.5% power. In a system where there is no static head component these relationships can be used directly to estimate the savings potential of reduced speed operation. However, as most real systems have some static head component, the relationships must be modified to account for this. In the example illustrated in Fig 16, at 40% speed, 40% flow would be produced through the system with no static head, whereas no flow would be produced through the system with static head.

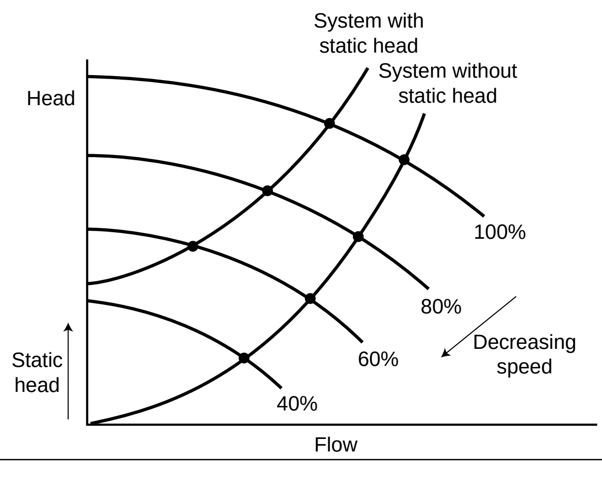

Fig 16 Effect of static head on reduced speed pumping

[2] Note that Fig 15 is correct only when the system head is entirely frictional, i.e. there is no static head component.

Appendix 3 shows in detail how motor and pump manufacturers' data, together with a knowledge of the system head:flow characteristics, and variation in flow requirement, can be used to assess the energy savings from using a VSD.

To make these calculations easier, there are software programs freely available from VSD suppliers for use on PC compatible computers. These programs require a minimum of input data and will select default information if users are unsure of the correct input.

The main benefits of pump speed control are:

- to facilitate matching pumping with flow requirements;
- to permit a tight control over pumped flows;
- to eliminate energy wasted by throttling the pumps;
- the inclusion of soft-starting.

The most common type of Variable Speed Drive employed on pumping systems is the pulse width modulated (PWM) **inverter**, although there are other types. The PWM inverter is very efficient and adds few further electrical losses to a pumping system. Unless the pumps are being driven at full speed constantly (in which case an inverter is unnecessary) then the potential savings can far outweigh any drive inefficiencies.

The control of a VSD can be manual, but is usually automatic, based on feedback signals from the system generated by measurement or control devices such as flowmeters, level indicators and pressure transducers. Some degree of interfacing may be necessary, especially for non-standard signals.

In multiple pump arrays it is normal for all pumps to run at the same speed so that their characteristics remain matched. This can be achieved by equipping each pump motor with a separate inverter, then using a common control signal. It is possible to mix variable speed pumps with fixed speed pumps, although the range of speed reduction available to the controlled pumps can be limited (depending on the system resistance).

The cost of Variable Speed Drives is relatively high, but continues to fall steadily. Furthermore, the cost savings benefits can often produce short payback periods.

Applications for variable speed pumping should satisfy both of the following conditions to produce the most attractive savings:

- the water demand is variable and less than 100% for long periods, allowing prolonged operation at reduced speeds;
- system resistance is mainly frictional, allowing operation at the lowest speeds (see Fig 16).

Note that if pumps always operate at less than 100% flow then they are too large. Selecting smaller pumps or trimming the impeller of an existing pump might be a more suitable alternative than a Variable Speed Drive, especially if demand variations are small.

4.4 Monitoring

4.4.1 *Pump Efficiency Testing*

Traditionally it has been difficult to measure pump efficiency under installed conditions. Obtaining the required measurements when faced with on-site difficulties and constraints largely precluded efficiency assessment once pumps had been installed. The development of a practical thermodynamic technique has solved many of these problems. It allows a direct calculation of efficiency in real time, solely from measurements of temperature and pressure increases across

the pump. This has been made possible by the development of sophisticated temperature probes capable of measuring only a few millidegrees. With simple temporary on-site installation of temperature and pressure probes at the inlet and outlet of a pump, the energy losses during pumping (i.e. the energy which is not converted to water flow and pressure) can be measured, and hence the efficiency of the pump calculated. In association, a measurement of the power input to the pump allows the flow rate to be calculated.

The results can then be compared directly with the manufacturer's characteristics for that pump to gain an indication of its true hydraulic condition. This not only shows whether the pump performance has deteriorated through wear, but shows whether or not the pump is operating in the region of peak efficiency. Furthermore, the inlet pressure measurement can detect possible NPSH problems which might cause cavitation, e.g. low inlet pressure due to partially blocked inlet filters. All individual pumps in a bank can be compared under similar conditions to identify the most economical combinations of pumps.

The equipment for conducting such tests was first packaged into a convenient form by Advanced Energy Monitoring Systems Ltd and was referred to as a **Yatesmeter.** Others are now available. Such a device provides a convenient means of obtaining valuable information about pumps and their operation as part of a system. Routine testing on most pumps can help to identify savings possibilities in terms of equipment maintenance, water control, operating hours, etc.

On vital pumping systems with large pumps, a permanent efficiency monitor installation might be appropriate to ensure that operation at peak efficiency is maintained.

4.4.2 *Pump Monitoring*

It would be beneficial to pump operators if all pumps were equipped with inlet and outlet pressure gauges and their motors fitted with ammeters. Inlet pressures can be monitored to ensure that inlet filters are not allowed to block and restrict the $NPSH_A$. Outlet pressure can provide some indication of how well a pump performs compared with its original characteristics (although the head/flow characteristic is usually quite flat making precise comparisons difficult). Ammeters can help in estimating pump running costs, although this requires an estimate of the motor power factor. For better comparisons with characteristics and estimates of running costs, flowmeters and kWh meters are more useful, but these are unlikely to be fitted except to large, vital pumps. By keeping regular records of readings from pressure gauges and ammeters, however, it should be possible to identify any changes in operation which may be indicative of problems or excessive energy use, e.g. increased power use or decreased pump pressure. Further details on this subject are available in GPG 112, *Monitoring and Targeting in large companies.*

A more sophisticated monitoring method is to employ a fixed efficiency monitor for continuous assessment of pump performance. This is an expensive option and can only be justified for pumps which are continuous high energy users and which must be kept in optimum condition. However, once tappings have been fitted to the pump inlet and outlet, spot checks using portable efficiency monitoring equipment can be conducted quickly and easily. These should aid problem diagnosis as well as providing information which can help improve pump or pumping system efficiency.

4.4.3 *System Monitoring*

For larger pump users it can be worth investigating sophisticated computer-based monitoring which can also provide some degree of control. The systems comprise remote out-stations where a range of monitoring signals, such as pressures, flows, currents, levels, etc., are read. In turn, several out-stations communicate with a base-station capable of producing graphic displays of system data and report printouts. The base-station can also generate alarm signals for any of the measured parameters, and in some instances can be used to control plant items, e.g. switch pumps on or off. The benefits of such monitoring are that a whole water system can be observed and its operation compared with plant activity. This enables the identification of opportunities to match pumping with requirements, as well as excess pumping, unnecessary pump operation and leaks. This kind of monitoring demands that pump and system documentation must be complete and up to date. Further details on this subject are available in GPG 31, *Computer-aided M&T for industry.*

5. CASE HISTORIES

This Section is a series of case histories that illustrate energy-saving techniques across a variety of pumping systems. Further, more detailed Case Study leaflets featuring energy savings made at a variety of sites are listed in the Bibliography.

5.1 Minimising Recirculation in a Works Water Supply System

A steelworks main water supply was fed from a high-level tank which was topped up continuously by a large supply pump drawing from a low-level freshwater tank, as shown in Fig 17. The works water consumption was around 1.5 million gallons/day, although this varied somewhat with production activities. A Yatesmeter test on the supply pump revealed that it was pumping close to 3 million gallons/day. The excess water from the high-level tank simply overflowed back to the low-level tank, i.e. up to half of the water being pumped was merely being recirculated.

As a solution the high-level tank was fitted with level controls to switch off the pump when the tank is full, and switch it on again before the tank empties. In this way an overflow should never occur and up to half of the pumping costs are being saved.

Initial pumping costs	£20,000/year
Estimated savings	£7,000 - 10,000/year (35 - 50%)
Estimated outlay	around £1,000
Estimated simple payback	<6 weeks

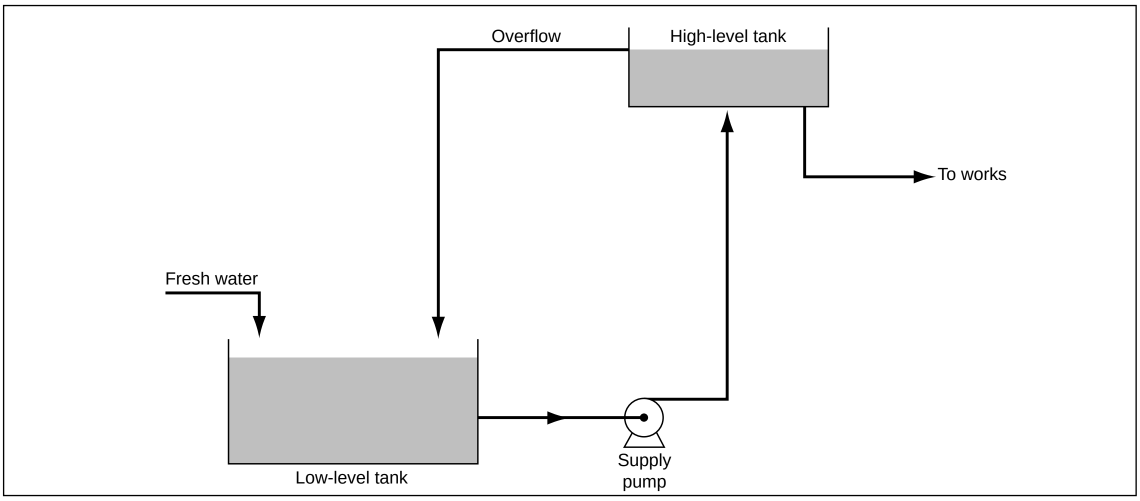

Fig 17 Schematic of works water supply pumping system

5.2 Dispensing with the Fourth Parallel-pump for Cooling

A bank of five parallel-pumps rated at 50 kW each was available to provide cooling water to a site. For some time it was considered that three pumps would provide adequate cooling, but more recently it had become standard procedure to use four pumps (though there had been no equipment or operational changes). From Yatesmeter pump efficiency tests it was found that the head and flow produced by each pump was close to the original performance curve, but through wear the efficiencies were around 10% lower than expected and consequently power consumption was higher at around 54 kW per pump. The annual running cost for four pumps was estimated to be £52,000/year.

By estimating a system resistance curve and superimposing this on a set of combined head/flow curves for four pumps, as in Fig 18, it was shown that the addition of the fourth pump did not add greatly to the total pumped capacity.

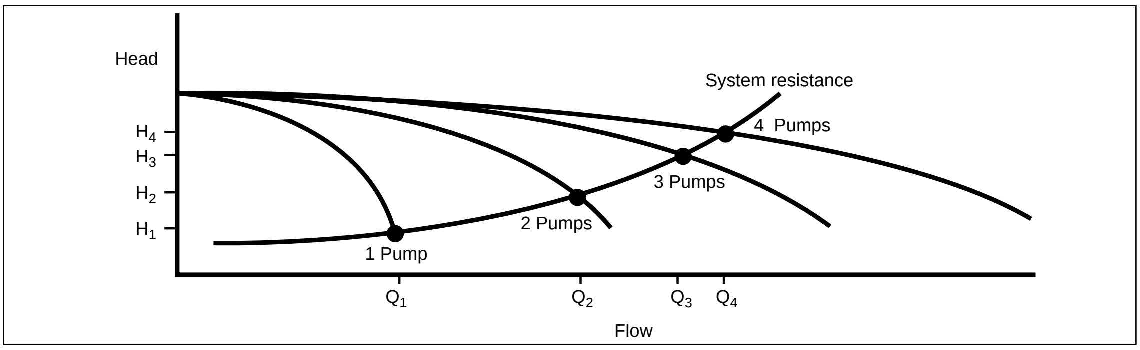

Fig 18 Combined characteristics of four cooling pumps operating in parallel

Potential savings for different options are indicated below:

Option 1: Revert to Three-pump Operation
Using the estimated curves it was deduced that operating with just three pumps would have provided around 91% of the four-pump flow while saving some 41 kW (19% of the original power requirement). At this works the saving was worth £10,000/year. Three-pump operation had been adequate in the past and the works personnel agreed that they could implement it again whilst considering other savings options. The modification of operating practice was very simple, immediate and involved zero cost.

Option 2: As Option 1, but Using Refurbished Pumps
The depressed pump efficiencies that were measured indicated that the pumps were in need of remedial maintenance. Refurbishment would have allowed them to operate more efficiently with a reduced power requirement. Although it was not expected that the efficiencies could be restored to that of new pumps, it was estimated that adopting three-pump operation with refurbished pumps would have increased savings to around 60 kW, worth £14,500/year. Note that in judging the relative merit of a case such as this it is only the extra savings (£4,500/year) that should be weighed against the extra costs (for the refurbishment of three pumps).

Option 3: As Option 1, but Using Three New Pumps
As an alternative to refurbishing old pumps, new pumps of the same type could have been purchased (whilst retaining the existing motors). This would have maximised the available efficiency and further reduced power requirements. It was estimated that by adopting three-pump operation with new pumps the savings could be increased to around 70 kW (33%), worth £17,000/year. The cost of three new pumps was in the region of £10,000. Therefore the payback based on the extra savings (over and above those from Option 1) would have been 1.5 years.

5.3 Operating With One Less Washing Pump

A bank of four parallel-pumps was available to provide water for washing purposes. One pump was almost large enough to deliver sufficient water, but not quite. Therefore, it was expected that two pumps would be used. However, if one of these two pumps were to fail, the other would assume a duty, not only beyond its efficiency peak, but also beyond the maximum power rating of its motor. Therefore it would trip-out and leave no water supply. As this water system is critical to furnace operation complete failure could not be tolerated. Therefore, three-pump operation was accepted as the norm. Total power absorbed was 634 kW which costs around £170,000/year.

The solution adopted here was to trim the impellers of the three pumps by a small amount such that in an emergency situation any one of them could run alone without tripping its motor, then to use only two pumps for normal operation rather than three. The third pump became the standby.

The impellers were trimmed at the machine shop of the works and other routine maintenance was conducted on the pumps at the same time. The total cost involved for three pumps was less than £10,000. The savings from this scheme were estimated at £44,000/year (26%) to produce a simple payback of around three months.

5.4 Variable Speed Drives on a Water Distribution System

The process water distribution system at the Creda Blythe Bridge works consists of a 6-inch cast iron ring main. The ring main is fed from two sources, Severn Trent water mains supply and a private borehole.

Originally the borehole pump was throttled to limit the flow to the permitted extract rate. A Pressure Relief Valve on the ring maintained a steady system pressure by controlling the recirculation back to the storage tank.

Fitting a VSD to the borehole pump and fully opening the throttle saved £2,450/year for an investment of £4,100, a payback of 1.7 years. Fitting a VSD to the Severn Trent water supply from the storage tank, allowed close pressure control of the ring main using feedback from a pressure transducer on the ring main. The old pressure relief valve was closed, and the pump speed is now automatically adjusted for correct water flow to meet the desired system pressure. This VSD cost £2,800 and gave energy savings of £3,460, a payback of ten months.

A more detailed account of the installation of VSDs on the water distribution system at the Creda plant and the energy savings made is included in GPCS 88, *Variable Speed Drives on water pumps.*

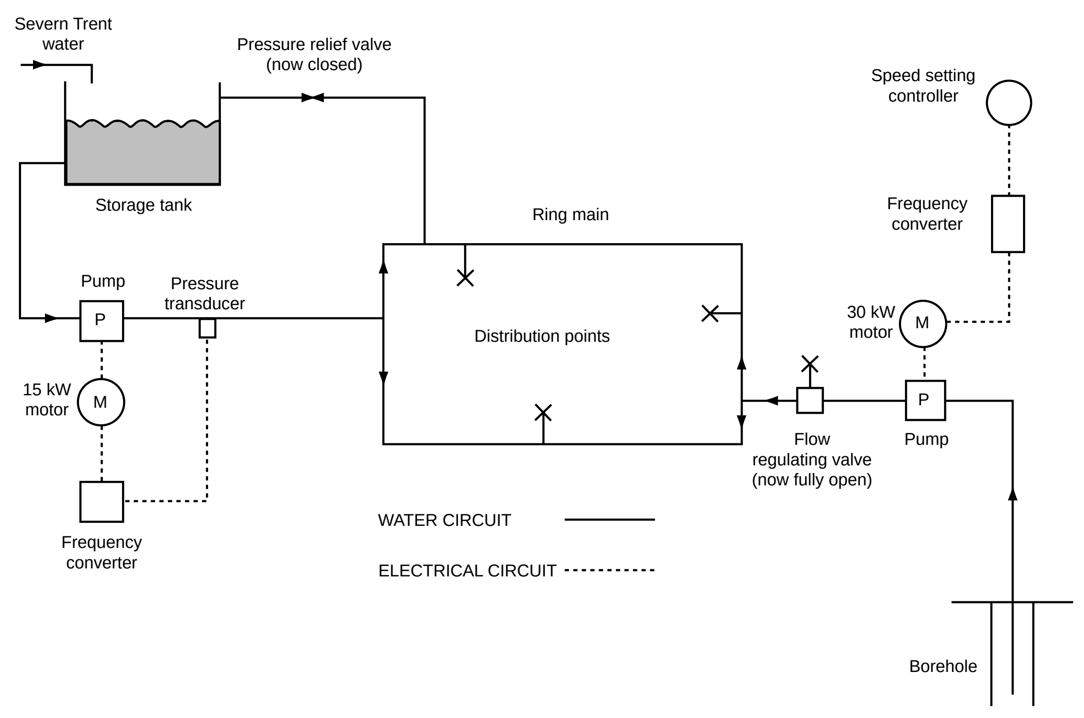

Fig 19 Water distribution system with VSD control

5.5 Eliminating Continuous High Volume Pumping to a Plate Mill Laminar Cooler

This particular project is New Practice Final Profile 79 from the EEBPP. Four parallel-pumps were available to supply water to a laminar cooler at a plate mill. The cooler reduces the temperature of hot rolled plate to within a target temperature band as the plate passes through it. A series of headers with many siphon nozzles (or upward sprays from below) direct water onto the steel. Different types and thicknesses of steel require different amounts of cooling and this is adjusted manually by an operator who sets the header array in use. Three or four pumps (depending on operator preference) were in continuous use so that energy use and pumping costs were not related to production, but were fairly constant. A simple schematic of the arrangement is shown in Fig 20. The pumping costs for this system were £86,000/year.

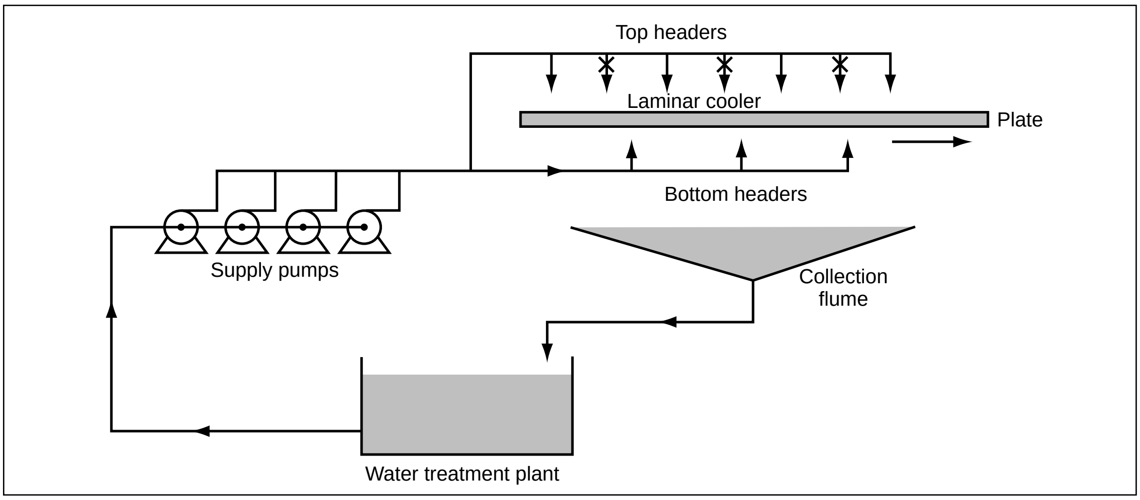

Fig 20 Schematic of plate mill laminar cooler system

The system was wasteful of energy for a number of reasons:

- water to unselected headers was diverted straight to flume;
- three of the top headers were never used, yet their water was also diverted straight to flume;
- water was still pumped throughout any delays or stoppages, or lengthy gaps between plates;
- the pumps were tested each weekend, then left running until the start of rolling, wasting around 16 hours of pumping every week.

The works decided to fit Variable Speed Drives to all four of the pumps and to introduce their operation in two phases.

Phase 1: On/Off Control
The Variable Speed Drives provided a soft-starting facility and it was only this feature that was used for pump control in Phase 1. Existing hot metal detectors before and after the cooler were used to provide control signals indicating hot plate approaching and leaving the cooler. In response, the pumps were run (at full speed) only when plate needed cooling, thereby dispensing with pump operation through non-production periods and weekends.

The energy use began to show a better correlation with production as displayed in Fig 21 and at the average production rate the savings would have been equivalent to 42%, worth £36,000/year.

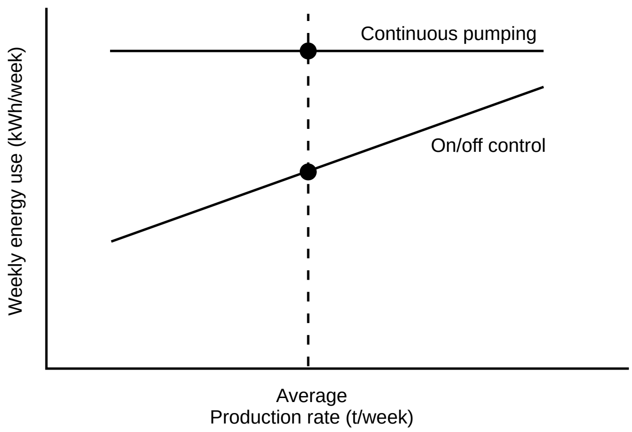

Fig 21 Illustration of energy savings from on/off control

Phase 2: On/Off Control Enhanced by Variable Speed Pumping

Once Phase 1 operation had been fully implemented the system was developed to the next phase where the existing on/off control was enhanced by using variable speed pumping to match cooling requirements. The divert routes from all headers (including those never used) were capped off to eliminate unnecessary recirculation. A simple algorithm was developed to select one, two or three pumps to match approximately the pumping with water demand (header array in use). The water flow was then finely adjusted by using a pressure feedback signal from the main supply manifold to control the common speed of those pumps. In this way, whatever the header selection in use, the pumping system was matched to it in terms of number of pumps in operation and their speed. At this stage the energy use and savings increased to 76% as illustrated in Fig 22, worth £65,000/year.

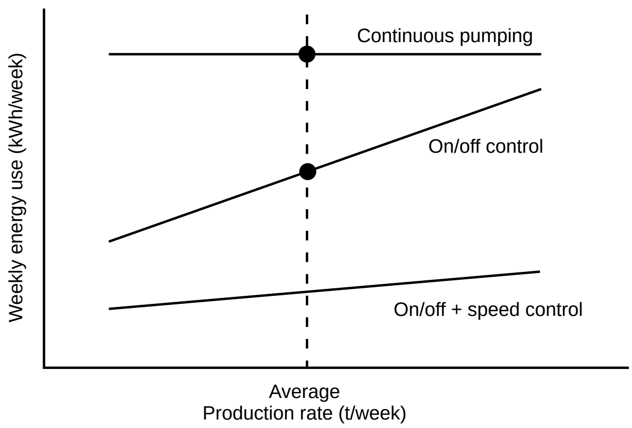

Fig 22 Illustration of energy savings from on/off plus variable speed control

The works had a high capital outlay for this project although this was largely because of the unsuitability of the existing equipment and its operating voltages. The simple payback period was 3.25 years, but could be expected to be significantly shorter for similar projects at other sites.

5.6 Increasing the Efficiency of Pumping for Continuous Caster Mould Cooling

A bank of three pumps was available to provide mould cooling water for a continuous slab caster. One pump was almost large enough to provide sufficient water, but not quite. Therefore two pumps were used, each absorbing 208 kW of power. Yatesmeter tests revealed that these pumps could only achieve efficiencies of at best 73% and as they ran against a throttle they were achieving efficiencies of only 66%. Annual running costs were £114,000/year.

In this case it was decided that an economical solution would be to purchase new equipment more suited to the water requirements. It was found that a single pump of the correct size could supply the desired amount of water to the caster while operating at an efficiency of 85%. It would absorb only 165 kW, representing a power saving of 60% worth £68,000/year. Furthermore, because the new pump was more efficient and could deliver more water with a lower power demand, the existing motor could be retained. The capital outlay for two pumps (one running and one standby) would have been around £12,000, although substantial pipework changes to accommodate them in the tightly packed pump house elevated costs. Nevertheless, a simple payback of only a few months was expected.

Before the project was progressed an uprating of the caster was announced and this increased the water demand. At this stage it was discovered that the upstream pressure on the flow control valves (which control the flow to each mould face) was higher than necessary. In fact, a 2 bar reduction in pressure could be tolerated. This relaxed the pumping requirement again so that a single pump (albeit larger than originally planned) would suffice. The savings from this scheme have been estimated at £57,000/year (48%) and a simple payback of well under one year is thought possible.

6. ACTION PLAN

6.1 Existing Water Systems

6.1.1 *Costs*

- Find out the costs of water, treatment, sewerage, electricity and estimate the cost of running all of the pumps on a system.
- Use the costs to justify retrofitting of energy-saving features.
- Use Monitoring and Targeting (M&T) techniques, if appropriate, for increasing awareness and controlling costs.

6.1.2 *Water Use*

- Find out where all the water is being used. Are all of the uses effective, or are some wasteful and even unnecessary?
- Identify the true maximum water requirements.
- Identify the variations in these requirements.
- Develop routine checks and information logging to gauge system water use and pump energy use trends.
- Find and eliminate water leaks.

6.1.3 *Systems*

- Minimise any diversion and recirculation from unused items of plant.
- Minimise pumping during process interruptions.
- Consider alternatives to throttling for flow control.
- Minimise other energy uses (e.g. from cooling tower fans) where possible.
- Check whether pressure upstream of flow controlling devices can be reduced.
- Fit control equipment to aid efficient system operation, e.g. level controls, thermostats, timer switches etc.
- Avoid static control of recirculating systems to achieve a fixed water balance. Aim for dynamic control which can quickly respond to changes in process activity.
- Ensure system documentation is complete and current.

6.1.4 *Pumps and Motors*

- Ensure that pump inlet pressures are adequate and that inlet filters are clear.
- Attend to any cavitating pumps immediately.
- Repair badly leaking seals.
- In parallel-pumping sets, check whether all running pumps are needed.
- If pump performance is in any doubt, seek an efficiency test.
- If pumps are due for overhaul, consider the benefits of applying an efficiency enhancement coating, or of purchasing new pumps.
- If pumps never reach their design duty, then they are too large. Fit smaller impellers or fit smaller pumps.
- If water requirements are intermittent then on/off control might be suitable. Check with motor manufacturers whether soft-starting is required.
- If water requirements show large variations then variable speed pumping might be attractive. Consult motor manufacturers about the suitability of retrofitting VSDs.

- Consider the control implications for the rest of a recirculating system if the supply pump operation is to be varied.
- If motors are due for replacement would smaller units of a lower power rating be appropriate (to save capital cost and possibly improve motor efficiency)?
- Use Higher Efficiency Motors in all new or replacement applications.

6.1.5 *Metering and Monitoring*

- Ensure metering equipment is functioning correctly.
- Fit appropriate metering devices where they are absent.
- Develop data collection routines to assess pump and system operation and trends.
- Consider the benefits of fitting an electronic monitoring system.
- Use M&T techniques where appropriate to identify and help maintain efficient operation.

Further details on this subject are available in GPG 112, *Monitoring and Targeting in large companies.*

6.1.6 *Maintenance*

- Use information from monitoring to identify problems and schedule maintenance.
- Take the opportunity to fit metering equipment when pipework is modified or replaced.
- Ensure pump inlet filters are kept clear.
- Maintain pumps to ensure efficient operation. Keep records of all pump maintenance.

6.1.7 *Training*

- Ensure pump and system operators have at least some basic knowledge of pumping principles.
- Ensure that data on energy use and savings achieved are freely available to operating staff and can be understood by them.

6.1.8 *Energy-saving Schemes*

- From available data develop ideas for energy-saving schemes.
- Get more ideas and information from the Energy Efficiency Best Practice Programme (see the Bibliography for details).
- Estimate savings potential, costs and payback potential.
- Seek support and funding.
- Publicise successful schemes.
- Replicate successful schemes.

6.2 New Water System Designs

6.2.1 *Costs*

- Budget for energy-saving features that will help save running costs.
- Find out the water costs and disposal costs - can these be minimised (e.g. by using lower grade water)?
- Find out the water treatment costs.
- Find out the electricity costs.
- Estimate the running costs and overall costs - use these to justify fitting energy-saving features.
- Consider the least expensive energy-saving features first (but initial expense must be balanced against cost savings).

6.2.2 *Water Use*

- Are there possibilities for using lower grade water?
- Can discarded water from another process be used for this one? Can water discarded from this process be used elsewhere?
- Check on specified water requirements to limit over-design and safety margins.

6.2.3 *Systems*

- Use a recirculating design, but minimise unnecessary recirculation.
- Minimise static head requirements.
- Design pipework for optimum water velocities (2 m/s).
- Minimise unnecessary system pressure drops.
- Minimise overpressure upstream of flow control devices.
- Avoid unnecessary system throttling.
- Avoid throttling as a means of flow control.
- Avoid sharp bends in system pipework, especially close to pumps.
- Use inlet and outlet flares.
- Ensure the provision of adequate $NPSH_A$.
- Aim to control supply pump operation to match process demands.
- For open-circuit systems use dynamic control so that return pumps can respond to changes in supply pump operation.
- For closed-circuit systems, design energy-saving features into the secondary circuit, e.g. thermostatic control of secondary pumps and cooling tower fans.
- Minimise additional energy use, e.g. cooling tower fan operation.
- Design water delivery nozzle arrays and stand-off distances for minimum water use and pressure requirements.

6.2.4 *Pumps and Motors*

Further details on this subject are available in GPG 2, *Energy savings with electric motors and drives.*

- Select pump sizes that match water requirements efficiently.
- Select pump sizes that use the largest (or close to largest) impeller size.
- Select pump sizes to match immediate water requirements rather than long-term future requirements.
- Select efficient pumps.
- Consider the benefits of internal coatings, especially efficiency enhancement (low friction) coatings.
- Obtain manufacturer's pump tests for each large pump rather than generic characteristics.
- Consider how variations or interruptions in water requirements can be most efficiently dealt with.
- If pumps are to operate in parallel then use as few as possible (within electrical constraints).
- Aim to operate pumps at, or close to, their design flow.
- Select motor sizes to correspond with pump design flow. Cater for ‘end of curve' operation only if this is likely to occur.
- Always specify Higher Efficiency Motors.
- Consider how pumps can be controlled to match water requirements efficiently.
- If on/off control is an attractive option check with motor manufacturers whether soft-starting is necessary.

6.2.5 *Metering and Monitoring*

- Ensure pumps and systems are equipped with adequate metering, e.g. ammeters, inlet and outlet pressure gauges.
- Fit kWh meters to large pump motors.
- Ensure critical pumping systems are equipped with reliable flowmeters.
- Make provisions for pump efficiency testing, i.e. fit pressure tappings at either side of pumps (according to recommendations from testing organisations).
- Consider installing a fixed efficiency monitor on critical pumps.
- Consider electronic monitoring on large systems where water costs and running costs are high.
- Make all pump and system details, together with water use specifications, available to pump and system operators.
- On commissioning, develop efficient water use and operating practices. Use these as ‘fingerprints’ or ‘benchmarks’ for continued efficient operation.

6.2.6 *Maintenance*

- Make provisions for quick and simple maintenance on all parts of the system, especially on pumps and their inlet filters.
- On commissioning, identify maintenance requirements and develop maintenance routines.

6.2.7 *Training*

- Ensure operators have an adequate knowledge of their system and its efficient operation. Further details on this subject are available in GPG 85, *Energy management training.*

7. BIBLIOGRAPHY

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7.2 Energy Efficiency Best Practice Programme Publications

Available free of charge from the EEBPP Enquiries Bureau at the address given on the back cover.

Good Practice Case Study 88, V*ariable Speed Drives on water pumps*
A summary of this Case Study is in Section 5.4.

Good Practice Case Study 89, *Variable Speed Drives on cooling water pumps*
The air handling unit (AHU) temperature on the large centralised chilling systems at Manchester Airport had been set by three-way valves diverting excess cold water back to the main chillers. Significant energy savings have been achieved by fitting VSDs to the chilling systems. Fitting variable flow valves controlled by the local temperature allows the pressure transducer controlling the cooling water VSD to detect changes in demand and so adjust the flow accordingly. The total investment of £49,600 produced savings of £26,800/year, giving a payback of just under two years.

Good Practice Case Study 124, *Variable Speed Drives on secondary refrigeration pumps*
The large secondary refrigeration system at Ind Coope’s Romford site was driven by a 75 kW pump, with a pressure regulator to bypass excess coolant. This system was inherently inefficient, particularly in cool weather. A VSD was fitted to maintain the set pressure automatically using a pressure transducer to control the pump speed. Energy savings of £7,960/year were achieved for a capital cost of £11,500, giving a payback of 1.5 years.

Good Practice Case Study 358, *Installation of Variable Speed Drives and small submersible pumps*
At the Hepworth Minerals and Chemicals’ Dingle Bank Quarry, annual energy savings of £12,180 were achieved on four pumping systems of 35 - 90 kW size. On three of the pumpsets the pump was replaced with a smaller one working nearer peak efficiency, and on two of the pumpsets a Variable Speed Drive was fitted The total cost of this work was £26,290, giving a payback on energy savings of 2.2 years, or 1.7 years when maintenance savings are taken into account.

Good Practice Case Study 170, *Variable Speed Drives in a chemical plant*
At its Newport works, Cray Valley Ltd uses large quantities of cooling water in the production of polymers and resins. When a hydraulic pump motor used to vary the speed on a stirrer was replaced by an 18.5 kW electric motor and a VSD, energy savings of £1,780/year were achieved. The changes cost £4,300 giving a payback of 2.4 years. VSDs were also fitted to pumps on two water cooling systems, thus allowing the flow to be altered to suit the demand. These VSDs cost £10,000 each and gave paybacks of 1.9 and 1.4 years.

Good Practice Case Study 300, *Energy savings by reducing the size of a pump impeller*
Maintenance problems caused Salt Union Ltd to look carefully at the operation of a pump on the condensate distribution system of the Runcorn salt production plant. It was found that it was too large for the actual duty, and so just £260 was spent on reducing the size of the pump impeller. This low-cost method of reducing the pump rating led to energy savings worth £11,900 a year, and allowed the 110 kW motor to be replaced by a 75 kW motor, making further energy savings. The payback on the impeller trimming alone was just eight days.

New Practice Final Profile 79, *Variable Speed Drives on a steel mill's water pumping system*
A summary of this profile is in Section 5.5.

CADDET Result 163, *Speed control of pumps saves energy at a pulp mill*
The Iggesund Paperboard AB Pulp Mill at Iggesund, Sweden, achieved energy savings of 18 kWh/tonne of pulp by fitting VSDs to the medium consistency pumps. Electricity consumption fell by 26%, while the overall payback was two years.

Good Practice Guide 2, *Energy savings with electric motors and drives*
This extensively revised publication contains information on all aspects of energy saving in motors and drives, with a particular emphasis on Higher Efficiency Motors and Variable Speed Drives.

7.3 Environmental Technology Best Practice Programme Publications

Available free of charge through the Environmental Helpline, telephone 0800 585794.

Good Practice Guide 67, *Cost-effective water saving devices and practices*

Good Practice Guide 25, *Saving money through waste minimisation: raw material use*

8. GLOSSARY

Cavitation	The formation and collapse of vapour bubbles, usually in an impeller entrance section, caused by insufficient inlet pressure. Thus in regions of high velocity the vapour pressure of the liquid is greater than the absolute pressure.
Centrifugal pumps	An impeller rotating at high speed within a stationary casing. The action of the impeller throws the liquid within the impeller towards the outside of the casing to generate pressure.
Coatings	Materials applied to the inner surfaces of a pump (those in contact with the pumped liquid) to form either a low friction surface to reduce pump losses, or a protective layer to reduce erosion/corrosion.
Efficiency	In a pump, the efficiency with which the shaft power applied (not the power to the motor) is converted to head and flow. Motor efficiency is the electrical equivalent of this parameter for the motor.
Flooded suction	The pressure at the pump inlet caused by the height of water above it. It is one of the factors which can contribute towards the $NPSH_A$. Note that if the pump is required to lift water towards its inlet, the flooded suction takes a negative value and is referred to as 'suction lift'.
Flow	The quantity of water passing an observation point. For pumped liquids the term mass flow is often used and refers to the mass of liquid passing per unit time. However, it is more common to use volume flow, i.e. the volume passing per unit time.
Friction losses	Pressure losses caused purely by the resistance of the pipework and system, which must be added to static head to obtain the total system resistance. Note that friction losses vary with flow rate and that they occur in pump inlet pipework as well as outlet pipework.
Head	The pressure generated by a column of water. The pressure difference generated across a pump is usually quoted in terms of the equivalent height of water.
Impeller	The term used for the rotating part of a pump which imparts the rotodynamic motion to the pumped liquid.
Inverter	The most common type of Variable Speed Drive where AC current is rectified to DC current, controlled then inverted back to AC current.
Multi-stage pumps	Pumps which contain several impellers, each feeding its output to the next stage in a serial fashion in order to generate pressures higher than a single-stage pump can achieve.
Neck rings	The rings attached to the casing which form a seal against the impeller between the high pressure and low pressure sections of a pump.

NPSH	Net Positive Suction Head: the total head at the pump inlet above vapour pressure. It usually has a subscript. $NPSH_R$ is the NPSH required by a pump at its inlet to prevent it from cavitating. $NPSH_A$ is the NPSH available from the inlet configuration in use. To avoid cavitation, therefore, $NPSH_A$ must be greater than $NPSH_R$.
Operating point	The point on a pump characteristic where the head/flow curve is crossed by the system resistance curve. This point will change if the pump performance changes (e.g. through wear) or if the system resistance changes (e.g. as a valve is opened or closed).
Power	Output from a motor is equal to the input power multiplied by the motor efficiency. It is this output power which is the power absorbed by a pump, i.e. the power value which features on pump characteristics.
Rated duty	The flow and head that are specified when obtaining a pump. These values appear on the pump nameplate. They should be close to the values corresponding to the peak efficiency of the pump.
Rotating element	The whole of the moving section within a pump casing.
Seals	Prevent water leaking outwards along the pump shaft. They can be packed glands or mechanical seals.
Soft-start	The action of gently accelerating a motor from rest to full speed in order to reduce high starting currents and shock loadings. It allows an increase in the frequency of re-starting.
Static head	The head of water a pump must overcome before it will produce any flow and is a result of the height difference between the suction water level and delivery water level.
Throttling	Used to impose a restriction in a pumping system, often by means of a valve to control the flow through the system.
Two-stage	Pumps using two impellers mounted on a common shaft with the outlet of the first feeding the inlet of the second. This series arrangement allows a two-stage pump to develop more pressure than a single-stage pump can achieve.
Vapour pressure	The pressure below which a liquid begins to form bubbles of vapour, and its value depends on temperature. The generation and collapse of such bubbles (similar to boiling) is usually termed cavitation.
Variable Speed Drive	A way of controlling the speed of a motor, usually electronically using an inverter. The speed can be varied manually, but is more often controlled via a signal from the process, e.g. pressure, flow, level, etc.

Velocity head	A measure of the kinetic energy possessed by some quantity of fluid in motion, in terms of the equivalent pressure of a column of water.
Yatesmeter	The name of the modern type of portable thermodynamic pump efficiency testing equipment developed by Advanced Energy Monitoring Systems (AEMS) and named after its inventor Maurice Yates.

APPENDIX 1

PUMP TYPES

A1.1 Pump Types

There are two main categories of pump defined by their basic principle of operation, namely rotodynamic and positive displacement pumps. However, these are broad descriptions and both types can be sub-divided, as shown in Fig 23.

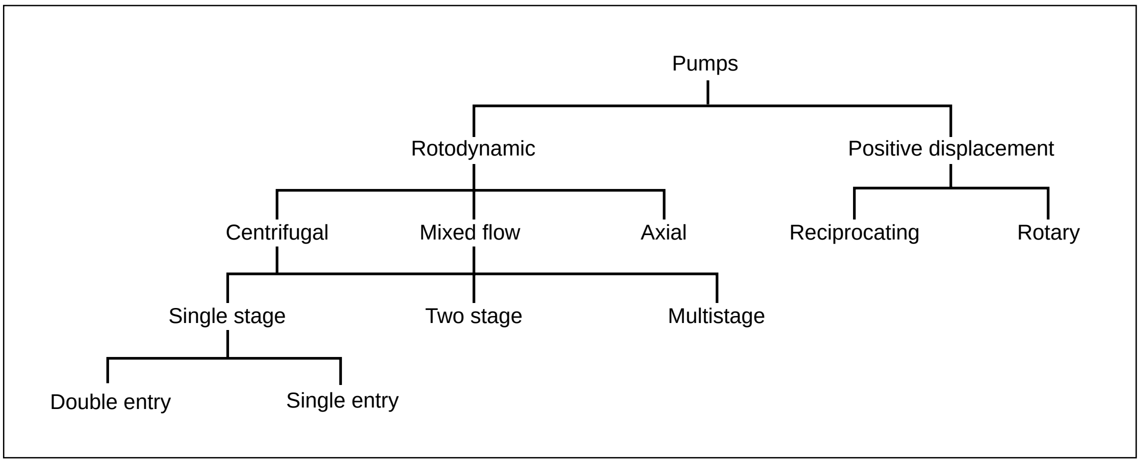

Fig 23 Pump types

Rotodynamic pumps generate pressure hydrodynamically. They use **impellers** which displace fluid by momentum, rather than positive mechanical travel. They are well suited to the high volume requirements of many industrial processes, especially the centrifugal type. For the lower capacity end of the application range the single-stage, single-entry pump is adequate, but for larger duties the single-stage, double-entry type of pump is favoured as it can achieve a superior **efficiency.** Furthermore, the single-stage, double-entry type of design facilitates maintenance, as the top cover of a horizontal split-casing pump can be removed to reveal the entire **rotating element** without disconnecting the inlet and outlet pipe.

For pressures higher than can be generated by a single-stage centrifugal pump, a **two-stage pump** using two impellers can be used, although for very high pressure duties, the number of stages can be six, eight, or more. Pumps with more than two stages are usually referred to as **multi-stage pumps.**

The types of pump normally used for the range of water pump duties in industry are almost always centrifugal. Small pumps are usually single-entry, but medium and large sizes are horizontal split-casing single-stage, double-entry or two-stage machines. For multi-stage machines the casing is usually split radially.

Positive displacement pumps generate pressure hydrostatically by reciprocating or rotary action. Reciprocating machines tend to be confined to high-pressure, low-flow duties. Rotary machines are less suited to developing high pressure due to internal leakage and practical size restrictions.

A1.2 Centrifugal Pump Operation

When describing a centrifugal pump it is simpler to consider initially a single-stage device. Two-stage and multi-stage pumps are essentially similar with the stages serially cascaded.

The illustration in Fig 24 shows a single-stage horizontal split-casing centrifugal pump with half its upper casing cut away to show the rotating element. As viewed, the inlet is to the right and provides water to the outermost chambers at both sides of the pump. This type of pump is referred to as a double-entry design, as the water from these chambers enters the eyes of the impeller from both sides.

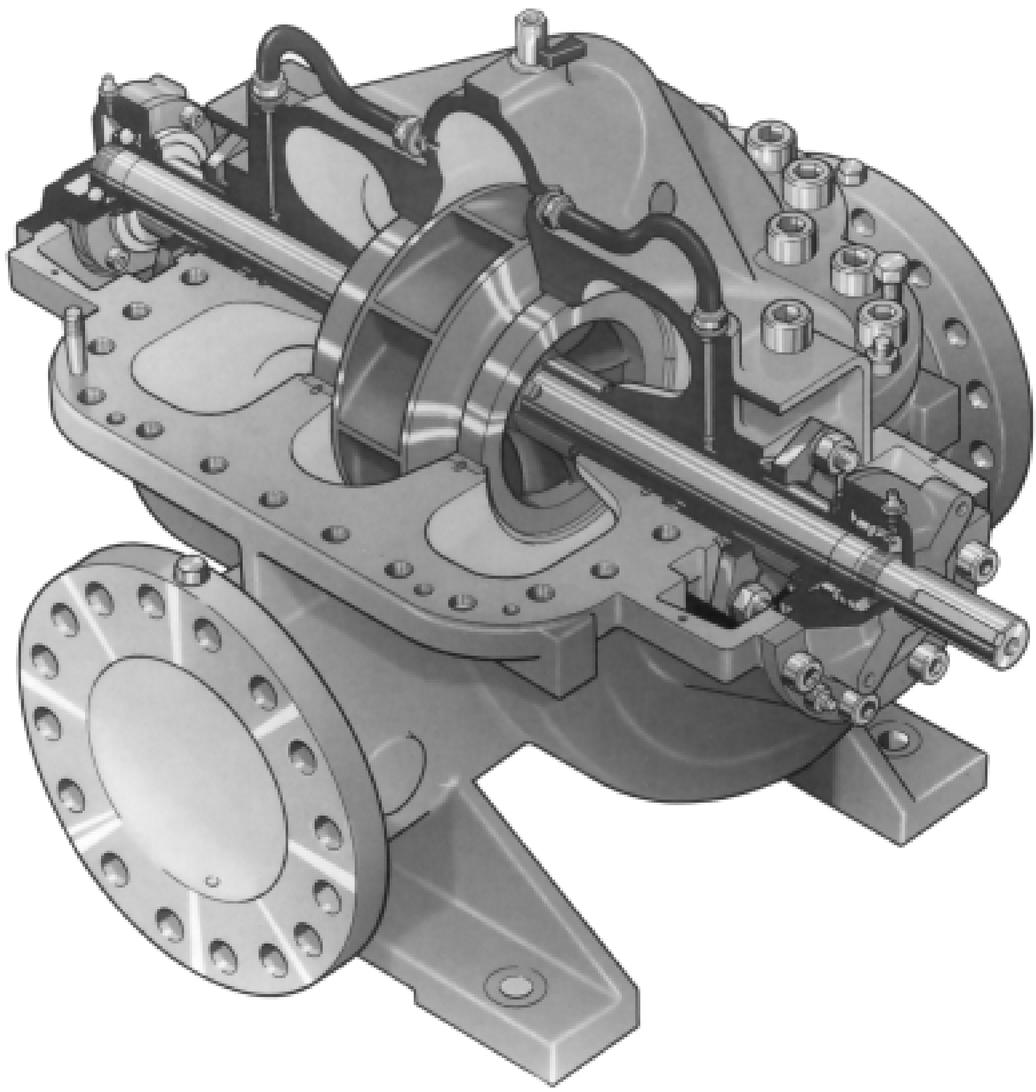

Fig 24 Single-stage double-entry split-casing pump

During rotation the internally vaned impeller throws the water towards its periphery to create a high pressure region, known as the volute, in the pump central chamber. The high pressure and low pressure chambers are separated by a **neck-ring seal** surrounding the impeller eye at each side. The volute is a spiral shape when viewed along the axis of the impeller, and forces water towards the pump outlet. Seals around the pump shaft prevent the leakage of low pressure water.

Fig 25 shows a two-stage axially split-casing pump with half of the upper casing removed.

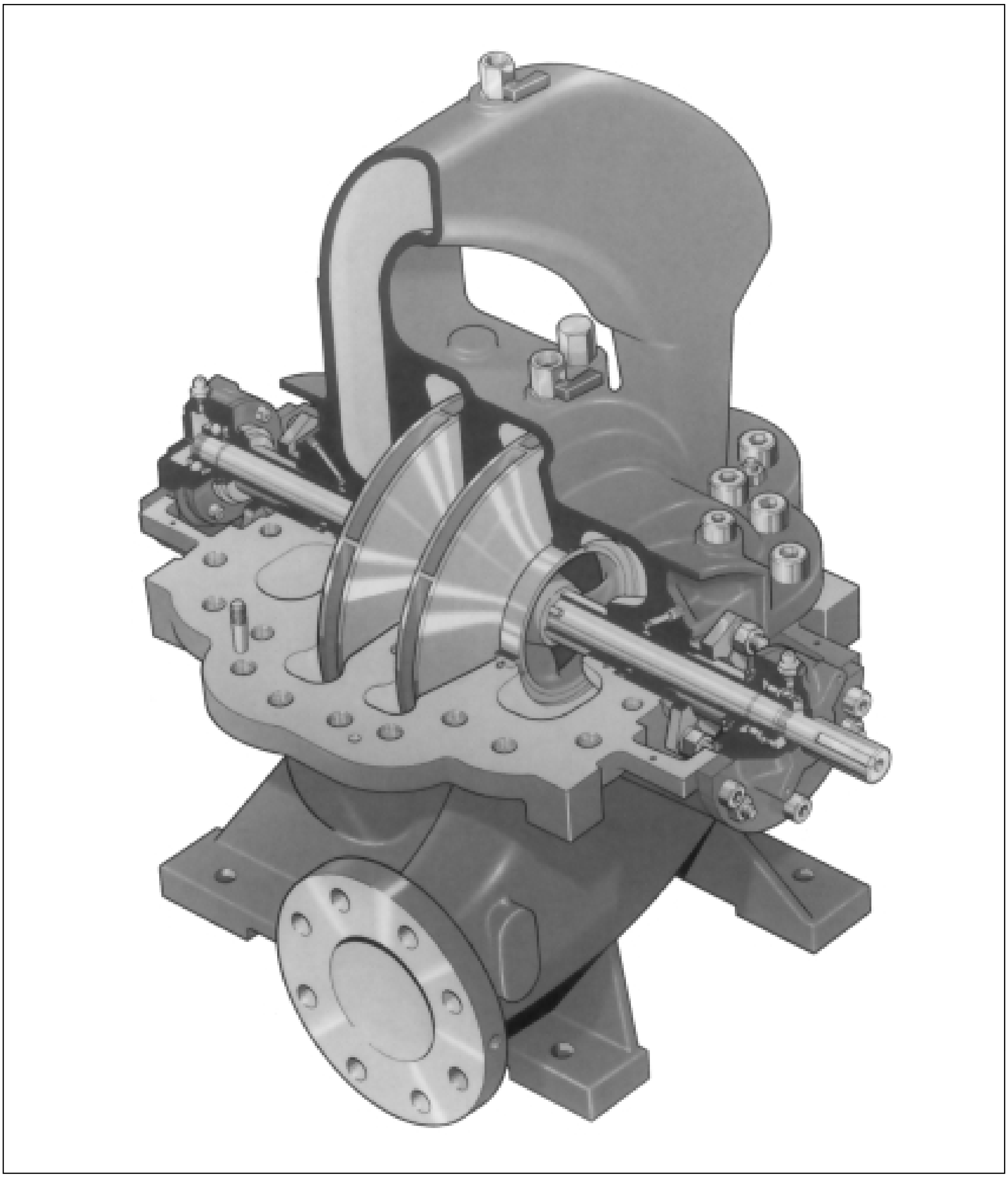

Fig 25 Two-stage axially split-casing pump

The pump inlet towards the front only provides water to the right side of the right impeller (as viewed), which is the first stage. The outlet from the first volute leads over the top of the casing to the inlet chamber at the left of the second impeller. The outlet from this impeller forms the main pump outlet which is hidden from view at the rear.

Fig 26 shows a multi-stage pump (five in this case) with an upper quarter of the casing removed to show the impellers mounted on a common shaft. The inlet section (towards the front left of the diagram) delivers water to the eye of the first impeller. It is thrown into the first diffuser chamber, which directs the water through internal passages to the eye of the second impeller.

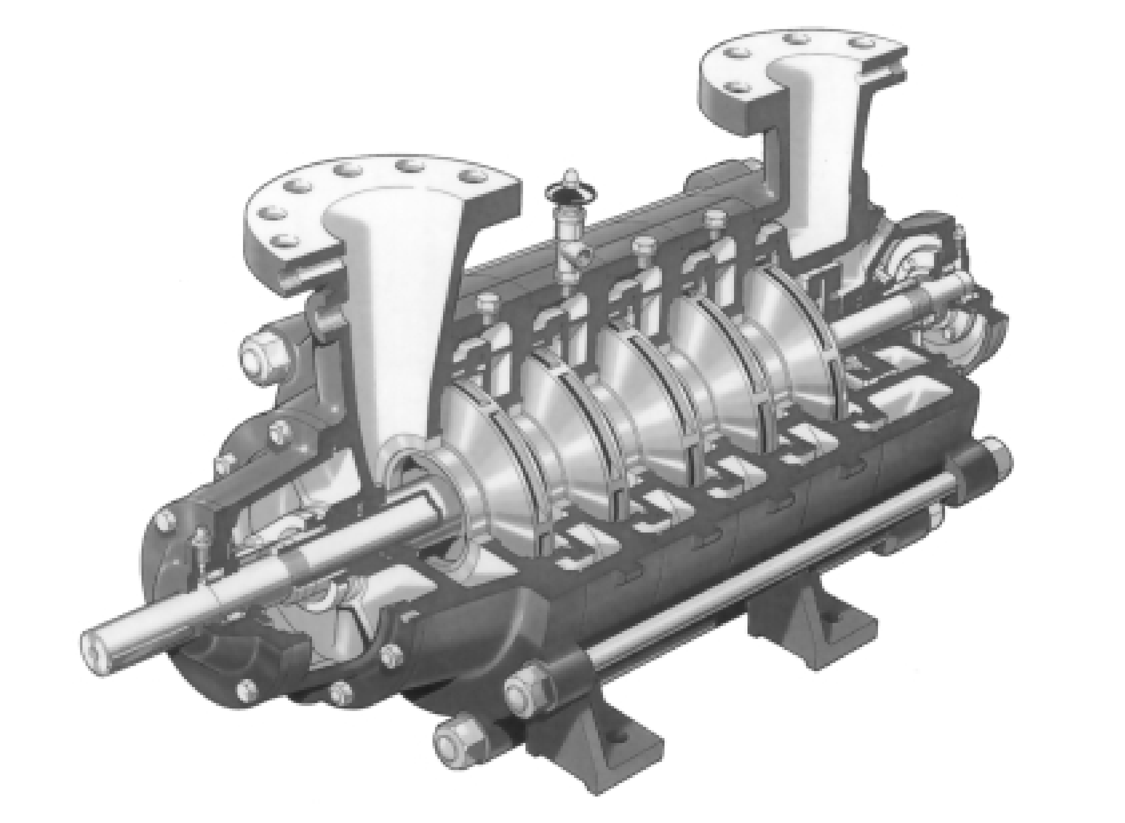

Fig 26 Centrifugal multi-stage pump

Successive stages operate identically until the final stage delivers high pressure water to the pump outlet.

A1.3 Pump Characteristic Curves

These appear in a number of forms, the most common of these is shown in Fig 27. This is simply a graphical representation of how the three main operating parameters vary with flow.

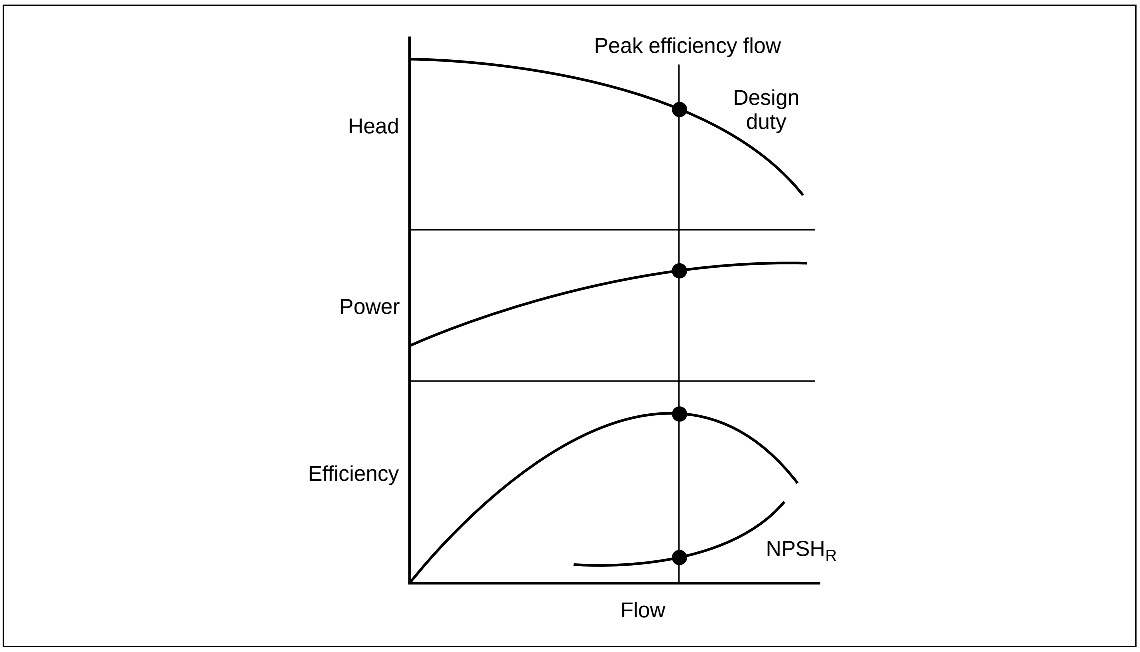

Fig 27 Centrifugal pump characteristics

It is important that these parameters and their interdependence are clearly understood. Proper system design leads to better performance and less maintenance, and energy efficiency can be built into the design.

Head - the equivalent pressure difference generated across the pump, i.e. the gain in equivalent pressure between the pump inlet and pump outlet.

Power - the power absorbed by the pump, i.e. the shaft power required to generate the pressure and flow.

Efficiency - is the efficiency with which the shaft power, or power absorbed, is converted into pressure and flow.

Flow - the flow through the pump. Note that the peak efficiency flow is that corresponding with the maximum efficiency value and is often referred to as the '*design flow*' of the pump.

The above parameters are related by the following equation:

$$\eta = \frac{Qgh}{w} \times 100$$

where η = pump efficiency (%)
Q = mass flow (kg/s)
g = gravitational constant of 9.81 ms^{-2}
h = head generated (m)
w = power absorbed (w)

Note that for cold water, where the specific gravity is 1.00[3], the mass flow in kg/s is equivalent to the volumetric flow in litre/s. Head is expressed in metres and is equivalent to the pressure generated by a column of water of that height.

Also shown on the characteristics is a curve labelled **NPSH$_R$**, or 'net positive suction head required'. The curve represents the minimum total head above vapour pressure required at the pump inlet (suction) to prevent **cavitation** from reducing the generated head (or pressure difference). To satisfy this condition it is necessary for the inlet pressure, or NPSH$_A$ (net positive suction head available), to exceed the NPSH$_R$. NPSH$_A$ can be represented as the arithmetic sum of all the factors contributing to the NPSH at the pump inlet, as shown in Fig 28.

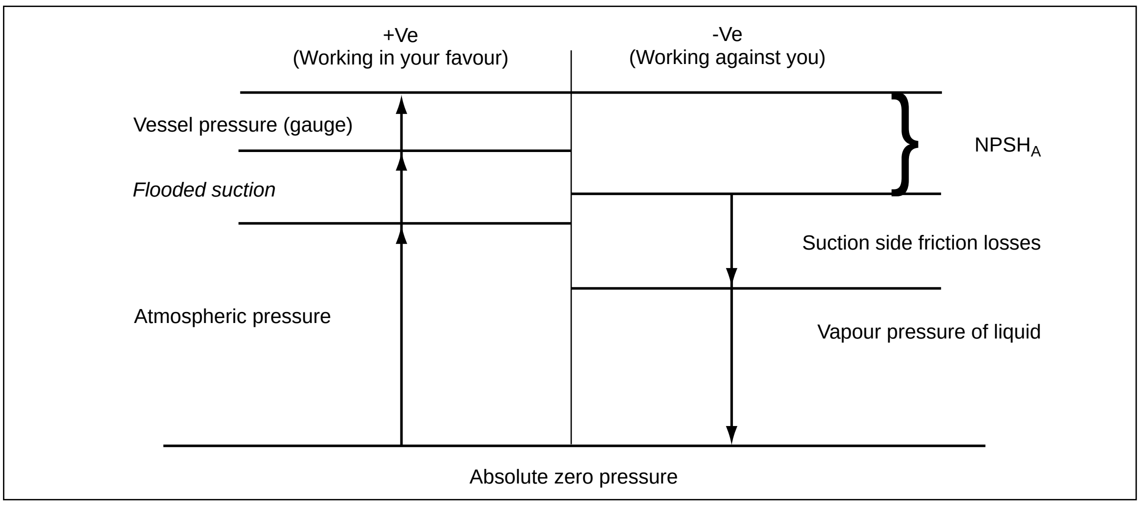

Fig 28 Illustration of NPSH$_A$

[3] Specific gravity of water falls to 0.96 at 100°C.

The important features of the $NPSH_R$ curve are:

- It increases at flows greater than the peak efficiency flow, making cavitation more difficult to avoid at high flows;

- It is usually extended in the low flow direction to flows of around one third (very approximately) of the peak efficiency flow. At lower flows the curve can exhibit a dramatic upturn caused by the onset of low flow cavitation.

Cavitation, besides reducing the generated head, can damage the internal pump surfaces and should be avoided. It is usually accompanied by an easily recognisable rattling sound. The head/flow curve in Fig 29 illustrates the onset of this and other events which can adversely affect pump performance when operating at flows well away from the peak efficiency flow.

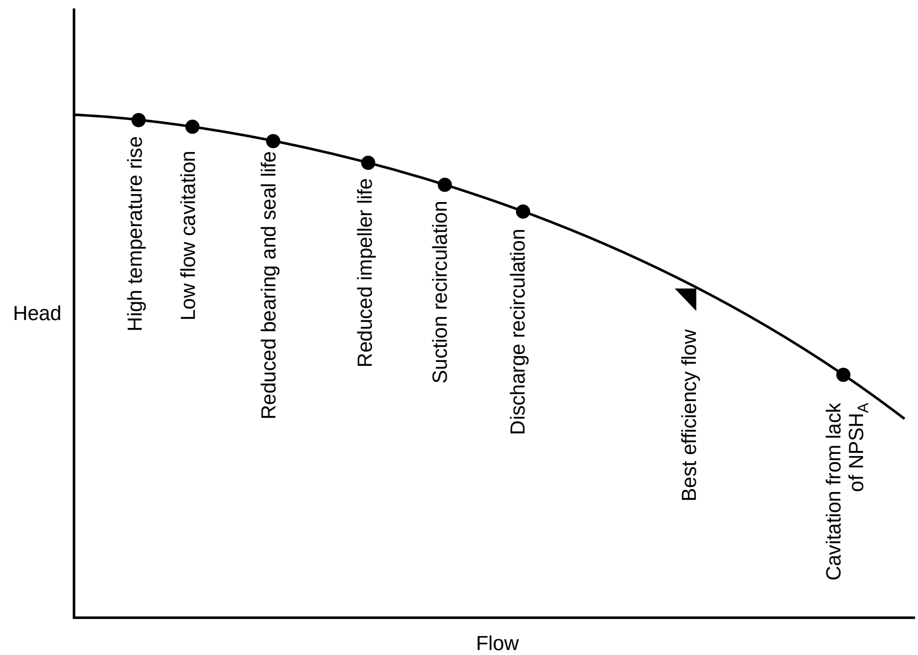

Fig 29 Onset of adverse effects when operating a pump away from its peak efficiency flow

Clearly it is important to try to arrange for pumps to operate at or around the peak efficiency flow for effective and efficient operation.

A1.4 Pump Combinations

A1.4.1 *Series Combinations*

If the outlet of one pump is connected to the inlet of a second pump, then a combined head/flow characteristic is obtained by adding the heads at each flow value, as illustrated in Fig 30.

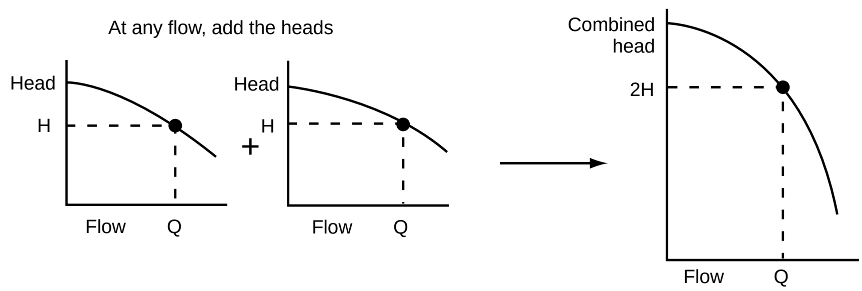

Fig 30 Combined characteristics of pumps connected in series

This is consistent with the fact that the head developed by a pump is the gain in pressure between its inlet and outlet. It is also the principle by which two-stage and multi-stage pumps operate to generate high pressures. Another common application of the principle is where a booster pump is used to generate a high pressure water supply from a low pressure feed. The combined curve for any two (or more) pumps can be obtained in this way, even if they are dissimilar. The combination will always produce a head and flow according to this curve. However, the addition of a pump in series does not necessarily add that pump's full pressure capability to the total generated. The total head (and flow) produced is governed by the system to which the pumps are connected.

A1.4.2 *Parallel Combinations*

If two pumps are linked in parallel so that their inputs feed from a common main and their outputs lead to a common main, then the combined characteristic can be obtained by adding the flows at each head value, as illustrated in Fig 31. This technique holds for any two (or more) pumps, even if they are dissimilar. Adding an extra pump in parallel does not necessarily add that pump's full flow capability to the total produced.

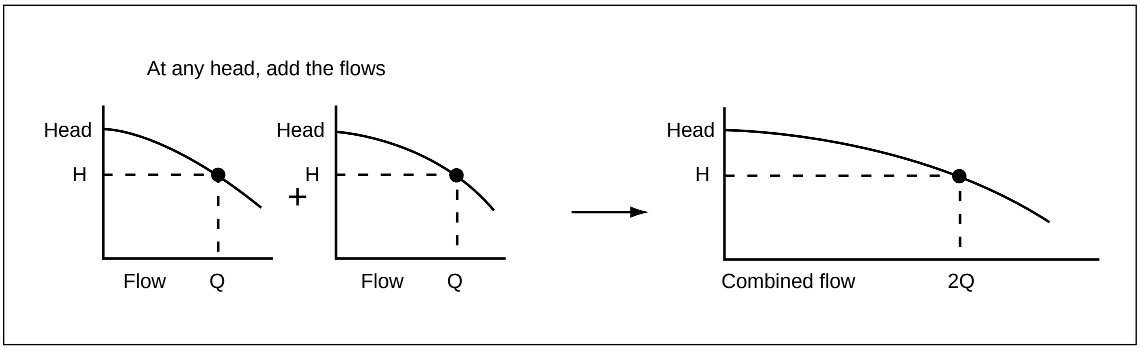

Fig 31 Combined characteristics of pumps connected in parallel

A1.5 Connecting Pumps to Pipework Systems

Delivering water to its destination requires some form of pipework system. To drive the water through the pipe, the pressure generated at the pump discharge is required to overcome the resistance of the pipework and system, and to raise the water through any height difference between suction water level and delivery water level. If there is no height difference, the system resistance is purely frictional and the flow that can be driven through the pipework will vary with applied pressure from the pump according to a square law, as shown in Fig 32.

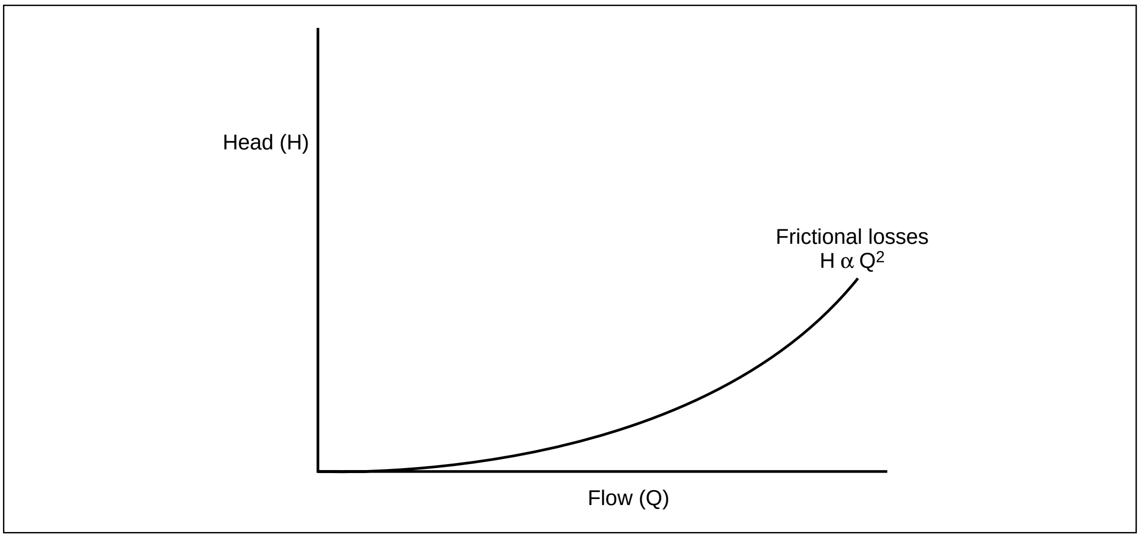

Fig 32 System resistance for frictional losses only

For most systems there will be some height difference between pump suction and delivery water levels. The pump will not deliver any flow until it has developed sufficient pressure to overcome the pressure due to that height of water, i.e. the **static head**. Effectively, the two components are added and the combined system resistance is as shown in Fig 33.

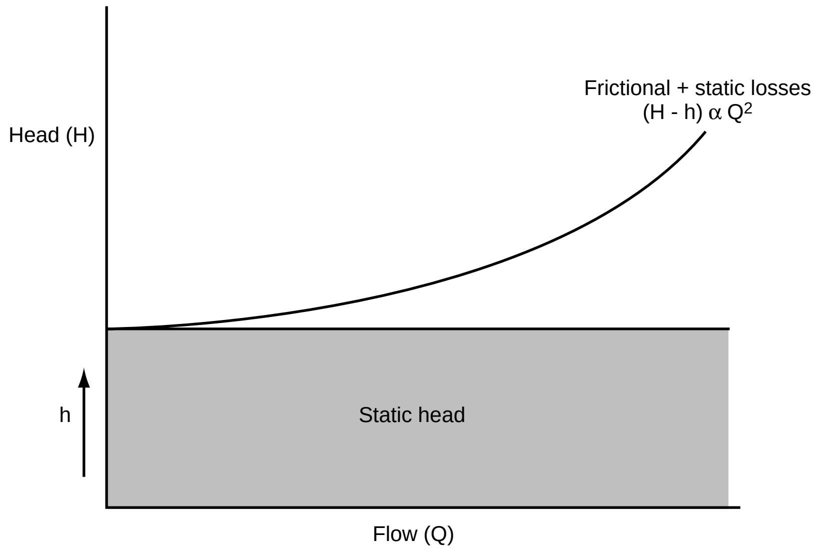

Fig 33 Total system resistance from frictional losses plus static head losses

The shape of the curve due to frictional resistance is dictated by factors such as the pipework diameter and its internal roughness, the number of bends and their curvature, and the degree of closure of any valves. An increase in system resistance caused by partially closing a valve in the delivery pipework will tend to increase the steepness of the curve.

A1.6 Operating Point

A pump (or combination of pumps) can only operate at pressures and flows according to its head/flow characteristic, similarly the system it connects to can only deliver water according to its system resistance curve. Therefore, the actual **operating point** can be found by superimposing the two characteristics, as in Fig 34.

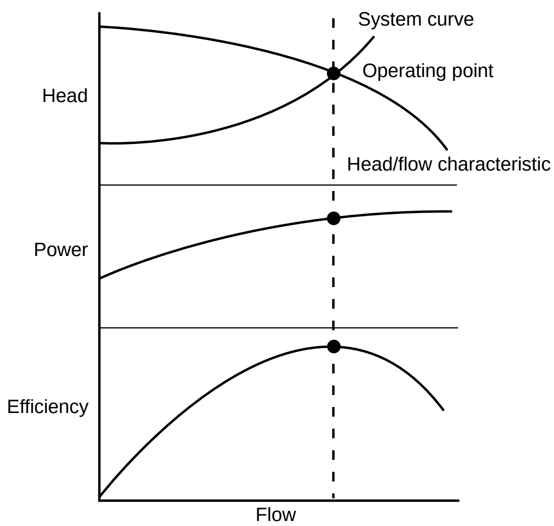

Fig 34 System resistance superimposed on pump characteristics

If the system resistance remains unchanged the pump will deliver the same flow, as shown by the point where the system resistance curve crosses the head/flow curve. The power absorbed and the pump efficiency at this flow are at points on the relevant curves vertically below the operating point. Ideally, the system resistance results in pump operation at, or close to, the peak efficiency flow.

A1.7 Pump Nameplates

Every new pump has a nameplate fitted to it. This shows details of the pump inlet and outlet flange size but more importantly, it shows the head and flow values which the pump should achieve, i.e. its **rated duty**. Note that these figures are matched with figures specified by the purchaser and might not correspond with the peak efficiency flow. The pump will be chosen by the manufacturer as the one with performance nearest to the requested specification. Usually, pumps can be matched so that they are capable of achieving an efficiency reasonably close to the peak value. Note that deterioration of pump performance over time will mean that an older pump may not actually meet the nameplate characteristics.

A1.8 New Pump Performance Tests

New pumps perform to a set of generic characteristics which can be confirmed if a test is requested on a particular pump. British Standard BS5316 gives a guaranteed acceptance limit for any pump test, although the limit varies depending on the classification of test standard. For a Class C test, the lowest classification, and also the standard by which many pumps are tested when bought, the following must be true:

- At the guarantee point, i.e. the rated duty according to the nameplate, the test curve must pass through an ellipse based on a ±4% head variation and a ±7% flow variation, as illustrated in Fig 35.

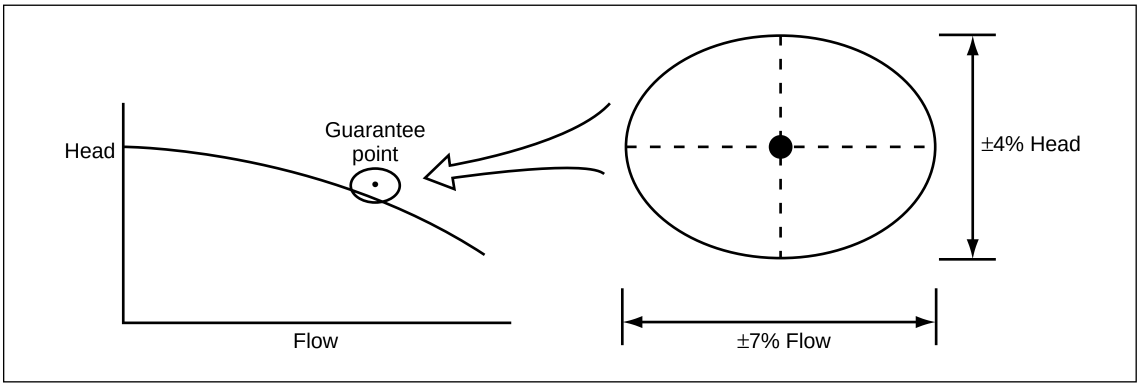

Fig 35 Illustration of the permissible margin on a Class C test guarantee point

- The pump test efficiency must be at least 95% of that stated at the guarantee point. Hence, a pump tested to Class C standard could show a test efficiency up to 5% less than expected.

Class B standard tests offer a tightening of these limits, but add to the price of a new pump.

A1.9 Summary of Potential Problems

From this brief look at some of the principles of pumping it is clear that there are a number of important features of pumps and their operation that should be considered if costs are to be reduced. These include:

- If the $NPSH_A$ (or pump inlet pressure) is insufficient then pump performance can be adversely affected and efficiency will be reduced.

- Cavitation should be avoided. It can dramatically affect pump performance and efficiency, and can also cause permanent pump damage.

- Operating pumps away from their peak efficiency flow not only reduces pumping efficiency but can invite other adverse effects.

- The duty point shown on pump characteristics is that specified by the purchaser and may not correspond with the peak efficiency flow.

- Pumps tested to Class C could show a test efficiency up to 5% less than may be expected from generic pump characteristics.

- Running costs form the major part of lifetime costs. Therefore it is important to keep efficiency high to save running costs.

- A 100 kW pump can cost between £20,000 and £30,000/year to run.

APPENDIX 2

USEFUL CONTACTS

A list of contacts for products and services is given below. The list is not exhaustive and has been compiled from information currently available to the Energy Efficiency Best Practice Programme. The listing of an organisation should not be regarded as an endorsement of its services or products by the Programme. Similarly, the Programme makes no claim for the competence or otherwise of any organisation not listed.

Pump Sales
Lists of equipment suppliers are published in the trade journals and by trade associations.

British Pump Manufacturers' Association
The McLaren Building
35 Dale End
Birmingham
B4 7LN
Tel No: 0121 200 1299

Motor and Drive Manufacturers and Suppliers
Lists of equipment suppliers are published in the trade journals and by trade associations. The GAMBICA Association publishes a list of suppliers of electronic Variable Speed Drive systems and a list of suppliers of electronic soft-start motor control systems.

The GAMBICA Association Limited
Westminster Tower
No 3 Albert Embankment
London SE1 7SW
Tel No: 0171 793 3000

For the Good Practice Guide *The repair of induction motors - best practices to maintain energy efficiency,* price £36, contact:

The Association of Electrical and Machinery Trades
177 Bagnall Road
Basford
Nottingham
NG6 8ST
Tel No: 01159 780086

APPENDIX 3

ESTIMATING THE ENERGY SAVINGS FROM FITTING A VARIABLE SPEED DRIVE TO A PUMP

The following steps will enable you to estimate - with reasonable accuracy - the potential savings from installing a Variable Speed Drive to a pump.

In practice, it is much easier and quicker to use one of the many computer programmes now available from VSD manufacturers. However, reading this Appendix will give you a thorough understanding of how these calculations are performed and the implications of any imperfections in your data.

It is not necessary for these calculations to be precise, they should just be good enough to give you confidence that the application will produce an acceptable payback. With a little experience, you will soon be able to identify pumps which could give good savings from the use of a VSD.

Start by looking for pumps:

- with long running hours;
- with larger motors;
- where the actual useful flow or head required from the pump varies.

The steps needed to estimate the energy savings from installing a VSD are illustrated with graphs relating to a worked example of a pump with steep Q/H (flow/head) characteristics.

Note that the graphs show % flow, head and power. Manufacturers will probably provide graphs in real units such as m^3/h, m and kW.

A: Obtain the Pump Characteristics

The pump manufacturer should be able to supply the data shown in Fig 36 which gives the total head against flow for different machine speeds and proportions of static head. (N.B. In practice the pump efficiency will reduce at lower speed.)

Select the curve for the proportion of static head in your application and read off the efficiency and head of the pump as the flow varies (at, say, 10% flow intervals).

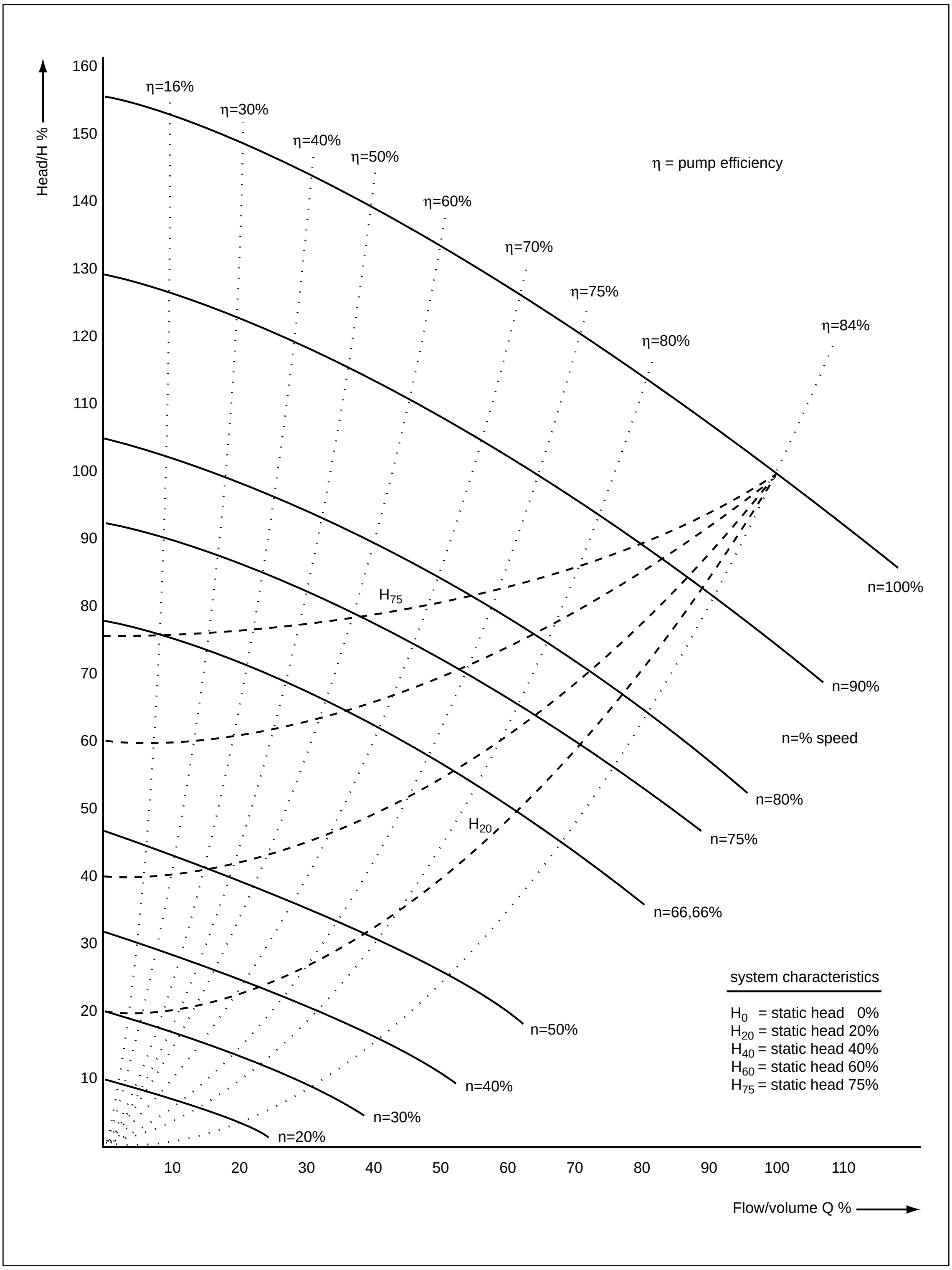

Fig 36 Examples of Q/H curves at different speeds and proportion of system static head, showing the variation in pump efficiency

B: Obtain the Motor and Inverter Efficiency Characteristics

The motor manufacturer should be able to supply you with efficiency:shaft power data. The inverter efficiency varies little with load, and is typically 95% - a value which should be used if no better data are available. Multiplying the motor efficiency characteristics by the inverter efficiency gives the curve shown in Fig 37.

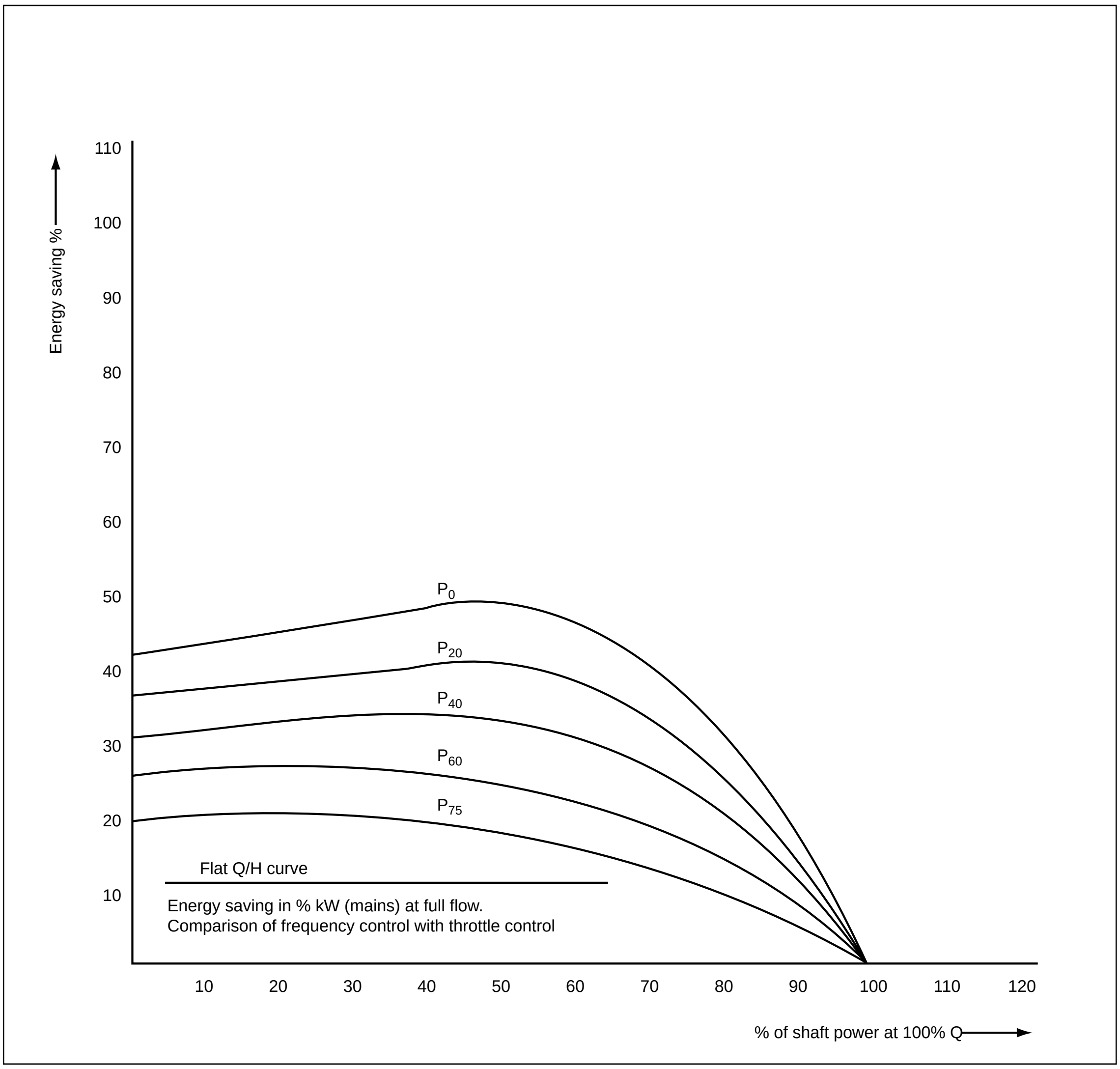

Fig 37 Example of efficiency/load relationship

C: Calculate the Power Demand of the Machine at Different Flows

The shaft power demand of the machine is obtained from the equation:

$$P = \frac{Q \times H \times Sg}{\eta p \times K}$$

where:
Sg = Specific gravity (Sg = 1 for cold water)
K = Constant depending on units (K = 368 if using kW, m^3/h and m)
ηp = Pump efficiency (%/100)

Read off the motor and motor/inverter efficiencies at the calculated shaft power for each flow step from Fig 37. Hence, by dividing the shaft power by these efficiencies, determine the related electrical power consumed (see Fig 38). (Note that the lower electrical power at 100% flow when throttling results from the absence of inverter losses.)

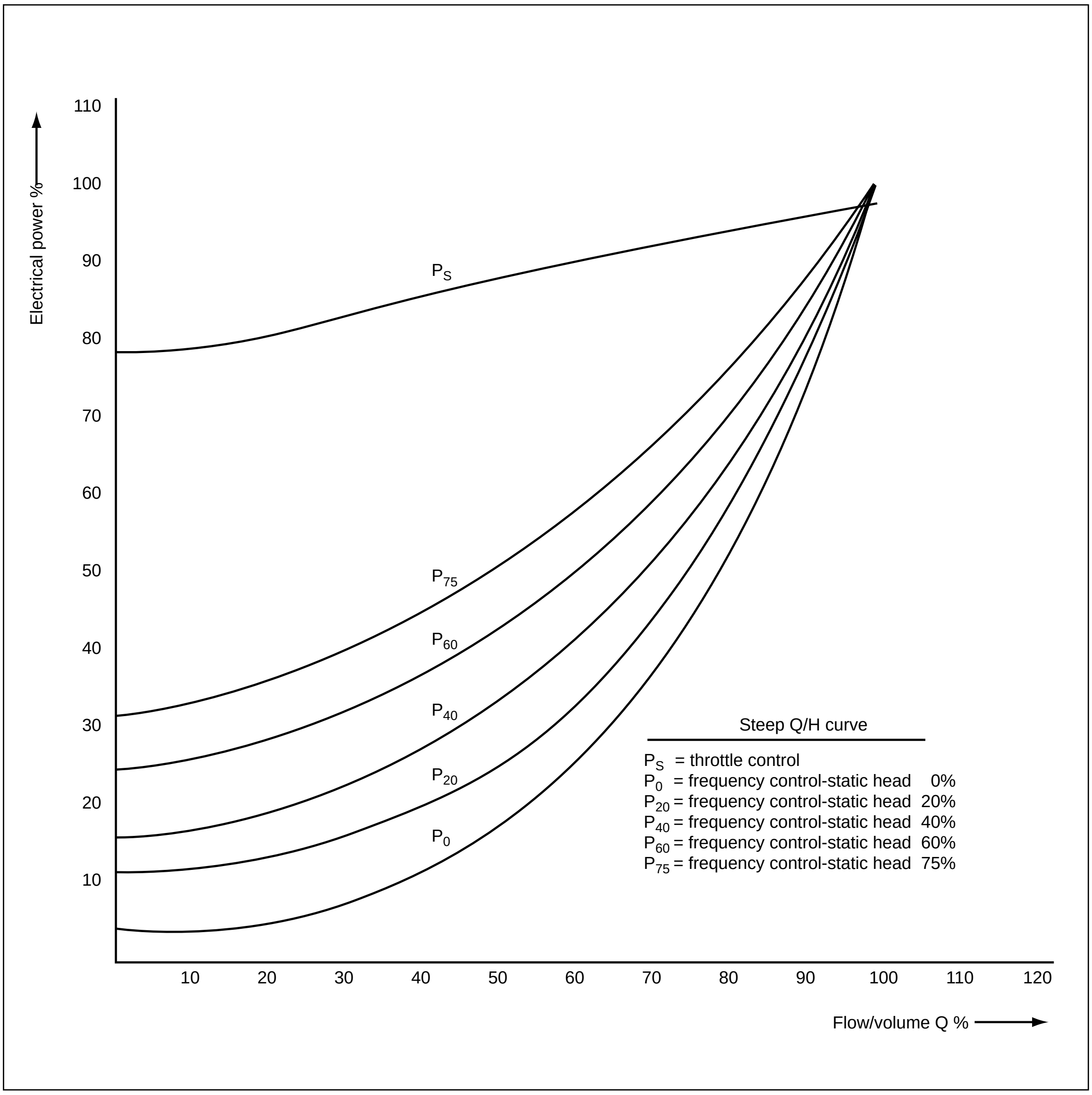

Fig 38 Electrical power consumed against flow, derived from Figs 36 and 37

D: Calculate the Power Saved by Fitting a VSD

Subtract the power consumption of the machine when using a VSD to control the flow from that with alternative methods.

In Fig 39, where VSD (frequency) control replaces throttle control, the power saving is graphically the difference between the P_0 to P_{75} curve and the P_S curve shown in Fig 38.

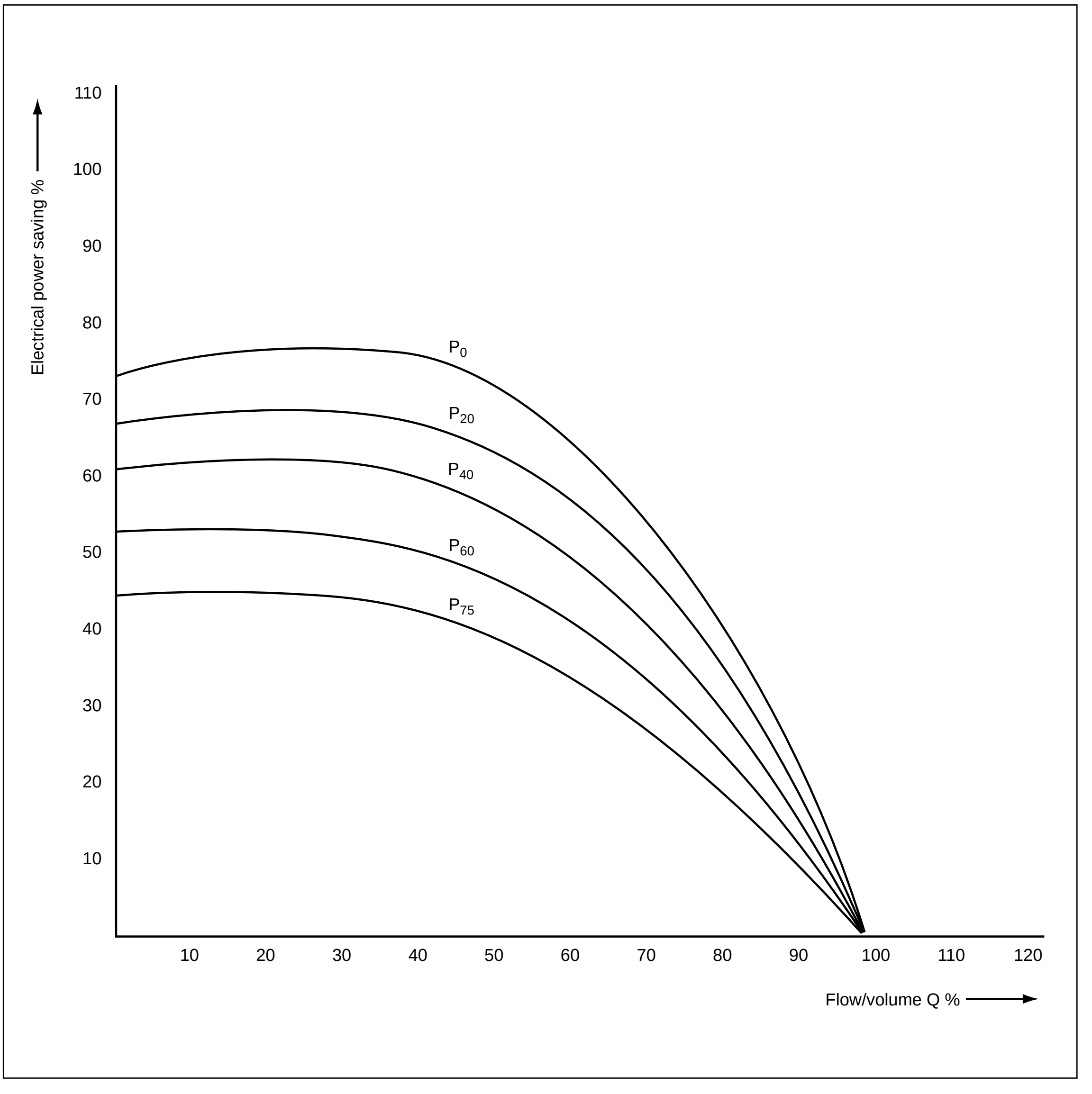

Fig 39 Electrical power saving with frequency control compared with throttle control, derived from Fig 38

E: Plot the Actual Flow Requirement

Plot the distribution of flow that is actually required. Most software programs use ten ranges for flow, i.e. 0 - 10%, 10 - 20% etc. Fig 40 shows an example of the flow distribution for pumps.

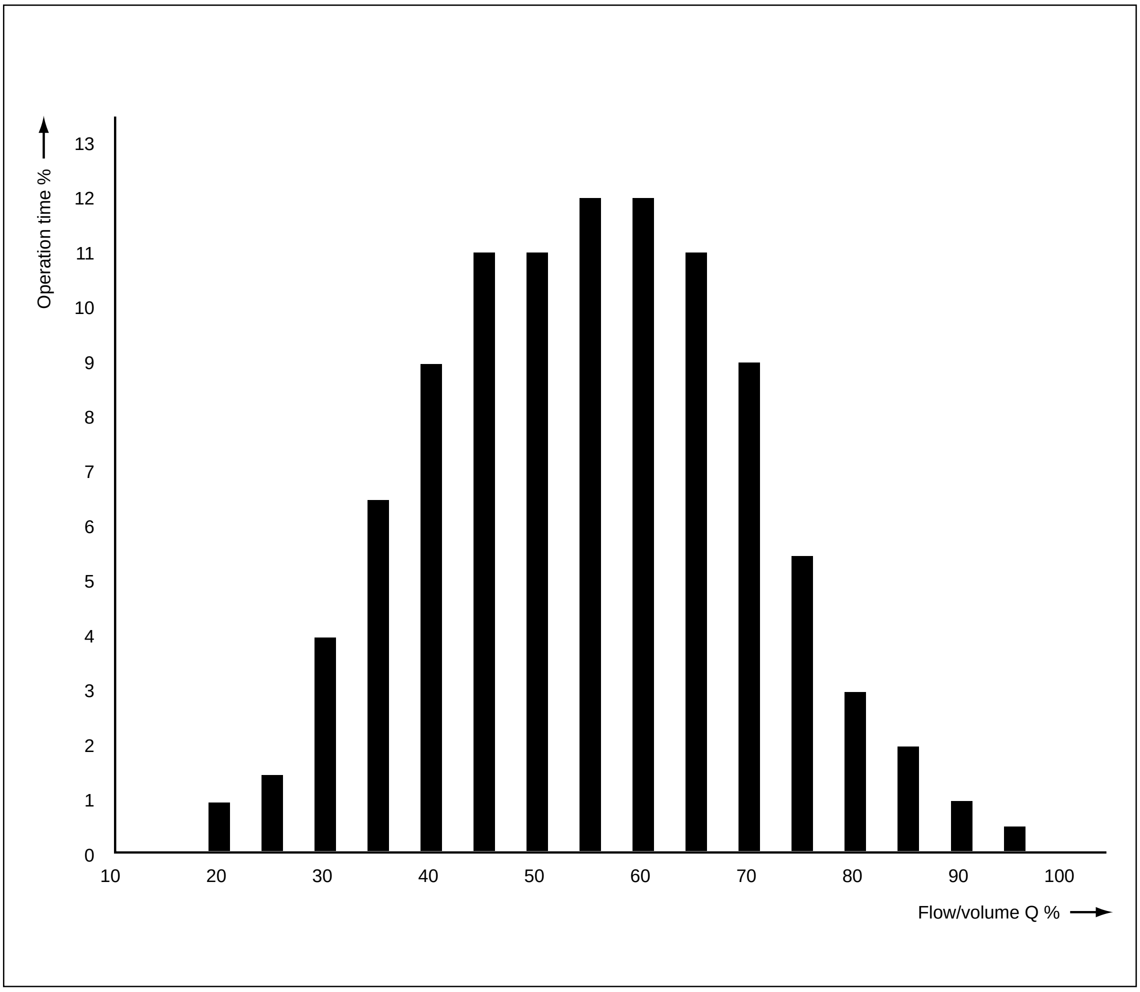

Fig 40 Example of pump operation

F: Calculate the Total Annual Energy Saving

In this example:

- static head = 20% of total head @ 100% flow;
- shaft power @ 100% flow = 90 kW;
- electrical power @ 100% flow with inverter = 102 kW;
- electricity cost = £0.05/kWh;
- operating time = 8,000 hours/annum.

For each flow band, calculate the energy saving by multiplying together:

- the percentage of the running time at each flow (see E);
- the power saving at that flow (see D);
- the annual running hours.

Obtain the total savings (see Table 1) by adding the energy savings at each flow:

Table 1 Total annual savings from installing a VSD

Flow (%)	**Electrical power saving from Fig 39 (%)**	**Operating time from Fig 40 (%)**	**kWh saved**
95	10	0.5	400
90	20	1	1,600
85	28	2	4,600
80	37	3	9,100
75	43	5.5	19,300
70	49	9	36,000
65	53	11	47,600
60	57	12	55,800
55	61	12	59,700
50	63	11	56,500
45	65	11	58,300
40	67	9	49,200
35	67	6.5	35,500
30	68	4	22,200
25	68	1.5	8,300
20	68	1	5,500
	Totals	**100**	**469,600**

G: Calculate the Annual Cost Saving

To obtain the annual cost saving, multiply the total energy saving by the cost of electricity.

In this example, annual cost saving = 469,600 kWh x £0.05/kWh = £23,480.

The Department of the Environment, Transport and the Regions' Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related topics please contact:
Enquiries Bureau
BRECSU
Building Research Establishment
Garston, Watford, WD2 7JR
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

For industrial and transport topics please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Tel 01235 436747
Fax 01235 433066
E-mail etsuenq@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R&D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.